PROCEEDINGS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. XXII.

JANUARY TO DECEMBER, 1896.

NEW YORK:
PUBLISHED BY THE SOCIETY.

1896.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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Vol XXII. JANUARY, 1896. No. 1.

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SOCIETY AFFAIRS.

CONTENTS:

MINUTES OF MEETINGS.

OF THE SOCIETY.

January 1st, 1896.—The meeting was called to order at 20 o'clock, Benjamin Reece in the chair; Charles Warren Hunt, Secretary, and present, also, Mr. John Thomson.

Ballots were canvassed and the following candidates were declared elected:

AS MEMBERS.

CHARLES FRANCIS CHASE, Providence, R. I.
GEORGE EDWIN GIFFORD, New York City.
CHARLES EDWIN GRAFTON, Chicago, Ill.
MALVERD ABIJAH HOWE, Terre Haute, Ind.
CHARLES MAYNE, Shanghai, China.
JOHN ALEXANDER MONTGOMERY, Birmingham, Ala.
DANIEL EDWARD MORAN, New York City.
DAVID SLOAN, Englewood, Ill.

As Associate Members.

Edwin Griggs Adams, Jr., Steelton, Pa.
Ernest Henry Brownell, Providence, R. I.
Joseph James Corti, San Juan, Argentine Republic.
Aquilla Ormsby Graydon, London, Canada.
Morris Knowles, Boston, Mass.
Antonio Esteban Mesa, New York City.
Alfred Walton Stockett, Mauch Chunk, Pa.
Gustave Robitscher Tuska, New York City.

No quorum being present, the meeting then adjourned to January 8th, 1896, at 20 o'clock.

January 8th, 1896.—The Society met at 20.20 o'clock, President George S. Morison in the chair; Charles Warren Hunt, Secretary, and present, also, 39 Members and 10 visitors.

Minutes of the meetings of December 4th and 18th, 1895, were adopted as printed in *Proceedings* for December, 1895.

Minutes of the meeting of January 1st, 1896, were read and approved.

The Secretary announced the election by the Board of Direction on January 7th, 1896, of the following candidates:

As Associates.

Peter Milne, Brooklyn, N. Y.
Joseph Agur Wells, New York City.

As Juniors.

Carmi Irving Bausher, Phœnixville, Pa.
Elmer Wallace Firth, Brooklyn, N. Y.
Arthur Stanlet Ives, Brooklyn, N. Y.

The Secretary announced the deaths of the following Members:

Russell Wadsworth Hildreth, elected Junior January 4th, 1888; died December 23d, 1895.

James Clarence Post, elected Member February 6th, 1878; died January 6th, 1896.

A paper entitled "Cost of Sewer Construction, Denver, Colo.," by W. W. Follett, M. Am. Soc. C. E., was read by the Secretary, who also read correspondence on the subject from Messrs. Andrew Rosewater, G. T. Nelles and William B. Landreth. The paper was discussed orally by Messrs. Foster Crowell, Henry Goldmark, George S. Morison and George R. Hardy.

Adjourned.

FORTY-THIRD ANNUAL MEETING.*

January 15th, 1896.—The meeting was called to order at 10.20 o'clock, President George S. Morison in the chair; Charles Warren Hunt, Secretary, and present, also, 150 Members and a number of visitors.

Messrs. C. J. H. Woodbury, G. W. Bramwell and Mace Moulton were appointed tellers to canvass the ballots for officers for the ensuing year.

Announcements concerning the sessions of the Annual Meeting and the points of interest which Members were invited to visit were made by the Secretary.

The Annual Report† of the Board of Direction for the year ending December 31st, 1895, and the Annual Reports of the Treasurer, Auditor and Finance Committee were read, and, on motion duly seconded, the report of the Board of Direction was accepted.

A report of the canvass of votes received for the place for holding the next Annual Convention was read by the Secretary, and the whole matter was referred to the Board of Direction with power.

Communications were read by the Secretary from Sandford Fleming, M. Am. Soc. C. E., Chairman of the Committee on Uniform Standard Time. On motion of Mendes Cohen, Past-President Am. Soc. C. E., a resolution was adopted petitioning the President, Senate and House of Representatives of the United States to accept and approve the sixth resolution adopted by an International Conference for the unification of time, which assembled in Washington in 1884, and to act in concert with other nations in this matter, and to cause the nautical almanac of the United States to be brought into harmony with this resolution at the beginning of the twentieth century.‡

The Secretary read a letter from Charles B. Dudley, M. Am. Soc. C. E., Chairman of the Sub-Committee, of the American Society of Civil Engineers, of the International Committee on Standards for the Analysis of Iron and Steel, reporting progress.

The Committee on Units of Measurement presented no report, but a letter from E. A. Fuertes, M. Am. Soc. C. E., Chairman, was, on motion duly seconded, accepted as a progress report, and on motion the Committee was requested to submit a final report at the next Annual Convention.

On motion of William H. Burr, M. Am. Soc. C. E., Chairman of the Special Committee on Uniform Methods of Testing Materials used in Metallic Structures, and on Requirements for These Materials to Further Improve the Grade of Such Structures, the last report of that

* A full report of the Forty-third Annual Meeting will be published in a subsequent number of *Proceedings*.

† See pages 7 to 22 for the Annual Reports of the Board of Direction, Treasurer, Auditor and Finance Committee.

‡ The full text of this resolution will be printed in a later number of the *Proceedings*.

Committee, printed in *Proceedings*, Vol. XXI, page 55, was accepted as final, and the Committee discharged.

The following report of the Board of Censors to award the Normal Medal was read by Palmer C. Ricketts, M. Am. Soc. C. E.

Report of the Award of the Norman Medal, 1894-95.

DECEMBER 5TH, 1895.

The Board of Censors to award the Norman Medal for the year terminating August 1st, 1895, unanimously award that medal to Paper No. 743, entitled "The Santa Ana Canal of the Bear Valley Irrigation Company," by William Ham. Hall, M. Am. Soc. C. E.

ROBERT MOORE,
C. W. RAYMOND,
PALMER C. RICKETTS,
Board of Censors.

The following report of the Committee to award the Rowland Prize was read by the Secretary.

Report of the Award of the Rowland Prize, 1894-95.

CHICAGO, JANUARY 10TH, 1896.

The Committee on the award of the Rowland Prize for the year ending August 1st, 1895, consisting of Charles Warren Hunt, Secretary, William Rotch and the writer, is unanimous in awarding this prize to William R. Hill, M. Am. Soc. C. E., for Paper No. 755, entitled "The Water-Works of Syracuse, N. Y."

Respectfully submitted,
C. L. STROBEL,
For the Committee.

The tellers appointed to canvass the ballot for officers presented the following report:

Report of the Tellers Appointed to Count the Vote for Officers, January 15th, 1896:

Total number of ballots received		411
Deduct:		
Not entitled to vote	1	
Without signature	10	
Voting twice	1	
Defective	1	
		13
Total found correct and counted		398

For President:

Thomas C. Clarke	390
George S. Morison	1
A. Fteley	2
J. F. Wallace	1
Blank	4

For Vice-Presidents:

William Rich Hutton	396
John Bogart	1
J. F. Wallace	1
Peter Alexander Peterson	392
C. L. Crandall	1
C. B. Comstock	1
Blank	4

For Treasurer:

John Thomson	398

For Directors, to serve three years:

District No. 1.—	George A. Just	392
	W. H. Breithaupt	1
	Theodore Cooper	1
	Blank	4
	William Barclay Parsons	394
	A. S. Tuttle	1
	Blank	3
	Horace See	396
	James Owen	1
	Blank	1
District No. 3.—	John R. Freeman	398
District No. 6.—	Daniel Bontecou	397
	William A. Haven	1
	Thomas William Symons	392
	Charles F. Loweth	1
	Blank	5

C. J. H. Woodbury.
G. W. Bramwell.
Mace Moulton.

The President announced that the following officers were elected for 1886:

President, to serve one year:

Thomas Curtis Clarke, New York City.

Vice-Presidents, to serve two years:

William Rich Hutton, New York City,
Peter Alexander Peterson, Montreal, Canada.

Treasurer, to serve one year:

John Thomson, New York City.

Directors, to serve three years:

District No. 1.—George Alexander Just, New York City.
William Barclay Parsons, New York City.
Horace See, New York City.
District No. 3.—John Ripley Freeman, Boston, Mass.
District No. 6.—Daniel Bontecou, Kansas City, Mo.
Thomas William Symons, Portland, Ore.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

January 7th, 1896.—Nine Members present.

Action was taken in regard to Members in arrears for dues.

The Annual Report for the year ending December 31st, 1895, was adopted.

The report of the expert accountant on the accounts and financial books of the Society was presented.

Resignations from the following Members were presented and accepted:

M. N. Forney, M. Am. Soc. C. E.
H. H. Kerr, Assoc. M. Am. Soc. C. E.
S. B. McKee, M. Am. Soc. C. E.
Fred. S. Young, Assoc. Am. Soc. C. E.
David C. Griggs, Jun. Am. Soc. C. E.
Henry Vier, Jun. Am. Soc. C. E.

Applications were considered. Two candidates were elected as Associates and three as Juniors. Other routine business was transacted.

Adjourned.

ANNOUNCEMENTS.

Wednesday, February 5th, 1896, at 20 o'clock, a regular meeting of the Society will be held, at which a paper by Desmond FitzGerald, M. Am. Soc. C. E., entitled "Flow of Water in 48-In. Pipes," will be presented. This paper is printed in this number of *Proceedings.*

Wednesday, February 19th, 1896, at 20 o'clock, a regular meeting of the Society will be held. The paper to be presented is by H. St. L. Coppée, M. Am. Soc. C. E., and is entitled "Bank Revetment on the Lower Mississippi." It is printed in this number of *Proceedings.*

ANNUAL REPORT OF THE BOARD OF DIRECTION FOR THE YEAR ENDING DECEMBER 31st, 1895.

PRESENTED AT THE ANNUAL MEETING, JANUARY 15TH, 1896.

The Board of Direction, in compliance with the provision of the Constitution of the Society, presents its report for the year ending December 31st, 1895.

MEMBERSHIP.

The changes in membership are shown in the following table:

	Jan. 1, 1895.			Jan. 1, 1896.			Losses.				Additions.		Totals.	
	Resident.	Non-Resident.	Total.	Resident.	Non-Resident.	Total.	By Transfer.	Resignation.	Dropped.	Death.	Transfer.	Election.	Loss.	Gain.
Honorary Members	5	4	9	4	4	8	..	..	....	1	....	....	1	...
Corresponding Members	....	3	3	....	3	3	..	..	....	...	....	....	....	...
Members	209	980	1 189	218	1 022	1 240	..	6	7	16	*20	60	29	80
Associate Members	42	144	186	56	181	237	9	1	....	3	†19	45	13	64
Associates	24	49	73	23	51	74	2	3	....	....	‡2	4	5	6
Juniors	87	179	266	90	188	278	30	2	1	2	....	47	35	47
Fellows	12	35	47	13	34	47	..	..	....	....	....	...	....	...
Subscribers	9	26	35	7	26	33	..	..	..	2	....	....	2	...
Totals	388	1 420	1 808	411	1 509	1 920	41	12	8	24	41	156	85	197

* 9 Associate Members, 1 Associate and 10 Juniors. † 1 Associate, 18 Juniors. ‡ 2 Juniors.

It will be seen by the table that the net increase during the year has been 112.

The total number of applications considered by the Board during the year has been 244.

Action has been taken as follows:

Passed to Ballot as Member	89
Passed to Ballot as Associate Member	82
Elected Associate	6
Elected Junior	49
Total	226
Awaiting action	52

The losses by death during the year number 24. They are as follows: One Honorary Member; John Newton. Sixteen Members; Frank Chester Beardsley, Frederick Janorin Carrel, Robert Linah Cobb, Eckley B. Coxe, James Gustavus Dagron, Pomeroy P. Dickinson, Horace La Fayette Eaton, Charles Fred Beals Haskell, William Abbott Pike, Orlando M. Poe, Willard S. Pope, Henry Frederic Rudloff, Frederick Ellsworth Sickels, Marshall M. Tidd, Arthur Mellen Wellington, William Howard White. Three Associate Members; William Sheldon Humphrey, John Frederic Temple, Charles Wood. Two Juniors; Stancliff Bazen Downes and Russell Wadsworth Hildreth. Two Subscribers; A. Chanute and William Henry Harris.

Library.

The following sums have been expended upon the library during the year:

Binding 40 volumes	$58 50	
Purchase of books	5 75	
Contingent expenses	6 33	
Total		$70 58
Total for previous year		388 23
Received from sales of duplicates		170 76

The additions to the library from all sources have been:

Bound volumes	223	
Unbound volumes	218	
Pamphlets	389	
Maps, photographs and charts	190	
Specifications	221	
Total additions during the year		1 141

The present number of titles in the library is 19 663.

Donations.

Attention is again called to the fact that the growth of the library is largely dependent upon legacies, and contributions of reports and other engineering literature, from Members, corporations and others who take an interest in the Society's welfare.

Society House.

The expenditure for repairs and betterments of the Society House has been $86 88.

The rooms have been kept open on Wednesday evenings during the year.

Exclusive of the attendance at meetings, 506 Members and others have consulted the library since September 1st, on which date a record was started.

A year ago your Board called the attention of the Society to the desirability of procuring enlarged quarters, and expressed the hope that the time might not be far distant when this enterprise might be

undertaken. During the earlier part of this year the subject was carefully considered by your Board, and on the 25th of May, 1895, a circular was issued setting forth the needs of the Society and the importance of early action. The replies to this circular were considered by the Board at its meeting at the Annual Convention, and were reported to the Society at the Business Meeting during the Annual Convention, together with the following resolution passed by the Board:

"*Resolved*, That the results of the canvass of the membership in regard to a new Society House be communicated to the Society at its next Business Meeting, together with the suggestion that, as the responses so far received are indicative of the feasibility of erecting a larger and more commodious building than that proposed in the recent circular, the Committee of the Society, if appointed, should be requested to take the fact into consideration in its action, it being the sense of the Board that a more liberal provision for the future needs of the Society than the circular suggested may be desirable."

The subject was discussed in the full meeting of the Society, which unanimously adopted the following resolutions:

"*Resolved*, That it is the opinion of the members of the American Society of Civil Engineers, assembled in Business Meeting June 20th, 1895, that the present quarters are insufficient, and that new and superior quarters should be procured.

"*Resolved*, That the execution of the scheme outlined by the resolution just passed be entrusted to the Board of Direction of this Society."

Under the authority thus given by the Society, the Board of Direction, after careful consideration, purchased the lots Nos. 218 and 220 West Fifty-seventh Street, having a frontage of 50 ft. on the south side of Fifty-seventh Street, New York, and an average depth of 110 ft., for $80 000. The deeds for this property have been taken in the name of the Society, $20 000 having been paid down in cash and $60 000 remaining on mortgage at 5% for two years, with the privilege of paying off the same at any time after one year. The location is considered specially favorable, and there is an opportunity for side lights on the east side. The authority for the purchase of this property and the sale of the present Society House was given by the Board of Direction on the 5th of November, 1895, by the unanimous vote of 26 Members, who constituted two-thirds of the whole Board. At this meeting it was voted, on motion of the oldest member of the Society, that the construction and architecture of the new Society House be entrusted to Members of the American Society of Civil Engineers and to none others.

Plans for a building specially adapted to the uses of the Society have been prepared by Joseph M. Wilson, Vice-President American Society of Civil Engineers. These plans provide for a reception room of about 1 200 sq. ft. area on the ground floor in front, and for a meeting room or theater, capable of seating about 400 persons, on the same floor in the rear. This arrangement provides full facilities for

meetings and entertainments in separate rooms, while the floor can be let out for other purposes than the uses of the Society, without interfering with any other portion of the house. The second floor, having an area of about 4 000 sq. ft., is arranged for the business purposes of the Society. The third floor provides a reading room of 1 600 sq. ft. in front, which will also be used as the library for reference books, and a book stack in the rear, capable of holding 150 000 volumes. Apartments for the janitor are provided in the basement. While it is believed that this will furnish all the accommodation which the Society will require for many years, it is proposed to construct the walls in such a manner that additional stories may be added if required. The building will be of fire-proof construction throughout. When not required for other purposes, the reception room on the ground floor can be used as a reading and conversation room for the Society. These plans will be exhibited for the consideration of the Society at the Annual Meeting. It is expected that the library will be kept open at all times until late in the evening for the use of Members and others.

The estimated cost of this building is $90 000, making the total cost of the building and lot $170 000, or $45 000 more than the plan proposed in the circular of May 25th. The difference is due to the larger facilities provided, and the proposed expenditure can be curtailed by completing only a portion of the house at once.

During the year the mortgage on the present Society House has been reduced, out of the revenues of the year, to $11 500, and it is perfectly safe to estimate the house as worth $50 000 more than the amount of the mortgage. The requirements for the completion of the new Society House, without appropriating any of the Society funds to this purpose, will be as follows:

Cost of house and lot.................		$170 000
Present Society House...............	$50 000	
Mortgage on new Society House......	60 000	
		110 000
Balance required.....................		$60 000

The Society has about $20 000 which could be expended for this purpose.

On the 18th of October, the Board of Direction issued a special circular describing the location and asking for voluntary subscriptions from Members and friends of the Society. In reply to this circular subscriptions have been received to the amount of $16 640, $16 365 from 221 persons connected with the Society, and $275 from 2 outsiders. When this subscription reaches $30 000 the success of the scheme will be assured; $60 000 will carry it through without the appropriation of any other funds for this purpose.

The subscriptions now referred to are absolute donations. When the scheme is more fully matured the Board of Direction will consider

the propriety of exchanging the mortgage on the property for an issue of mortgage bonds bearing a low rate of interest, to be taken by Members of the Society.

The income of the year 1895, over and above all ordinary expenditures, was $8 715 12. The new Society House, with its improved facilities, will add to the expenses of the Society, but the addition is not expected to exceed $3 000, which is less than one-half the surplus for the present year, and is equivalent to the yearly dues of 200 Non-Resident Members.

PUBLICATIONS.

The following table gives in detail a summary of the publications issued during 1895.

	Number issued.	Total edition of each number.	Number pages.	Plates.	Cuts.
Transactions	13	2 300	1 252	52	207
Proceedings	13	2 300	239	..	..
Indexes and Table of Contents	8	2 300	94	..	..
Advertisements	13	2 300	155	..	..
Bulletin	18	1 950	119	..	..
Constitution and List of Members	1	2 400	170	..	..
Reprints	4	300	134	13	..
Totals	...	....	2 163	65	207

The cost of publications has been:

For Paper, Printing and Binding *Transactions* and *Proceedings*, Indexes, etc		$6 087 88
For Plates and Cuts		720 94
Folding and Inserting Plates		81 22
For Copyright, Wrappers and Sundry Expenses charged to Publications		106 25
For Commission on Advertisements		296 00
For 18 *Bulletins*		267 00
For 13 100 Advance Copies of Papers		399 28
For 8 775 Extra Copies of Papers		625 99
For 850 Extra Copies of Memoirs		45 90
For Reprinting one number and three early Papers of *Transactions*		351 29
For List of Members		763 28
Total		$9 745 03
For time of Officers, Clerks and Stenographers, charged to Publications		2 861 64
Total		$12 606 67
Deduct amount received for Advertisements	$1 952 50	
Deduct amount received for Sale of Publications	2 379 93	
		4 332 43
Net cost of Publications		$8 274 24
Net cost of Publications for 1894 (see Report of the Board of Direction January, 1895)		8 941 42

It is of interest to note that the net cost of publications per Member of this Society was $4 36 for 2 008 pages, or about one-fifth of a cent per page.

With the number for January some modifications of form were introduced: New style of covers for *Transactions* and *Proceedings*, using the new Society badge as a distinctive mark; marginal notes in the full record of Business Meetings, giving the subject-matter under discussion, and in the discussion and correspondence, giving the name of each contributor.

As far as possible, the wax process has been used for illustrations, thus substituting for large folding plates cuts which could be printed as part of the text. The result has been that the saving in size and printing has more than balanced the increased cost of the process, while the charges for inserting and folding plates have been very greatly reduced. Moreover, the appearance and character of the publication have been materially improved, while its form is more compact and convenient. The economical results are shown by the following table :

All Publications (Charges for Time of Employees Excluded).

	1893.	1894.	1895.
Total pages published	2 525	1 748	*2 008
Total cost, including illustrations	$17 542 77	$10 876 81	$9 745 03
Number of copies of *Transactions* and *Proceedings* printed—			
Jan. to June	2 200	2 200	2 300
July to Dec.	2 500		
Average cost per page	$6 95	$6 22	$4 85

The actual advantage to the Society, upon exact reference to cost per page, shows a saving of about 30% per page on the cost for 1893, and 22% on that for 1894, which is largely due to the use of this system of illustration.

Beginning with the January number of 1896, the new system of publication † will go into effect. This scheme has been framed with special reference to prompt publication, to securing more thorough discussion of papers, and to placing the final issue of *Transactions* in a form convenient for preservation by Members.

Meetings.

The Annual Meeting, held in New York January 16th and 17th, 1895, was attended by 274 of the Society Members and by many of the ladies of their families.

* Does not include advertising pages, as they were not counted in previous years.

† See minutes of meeting of November 6th, 1895, *Proceedings*, Vol. XXI, page 210.

The attendance at the 27th Annual Convention, held at the Hotel Pemberton, Hull, Mass., was the largest in the history of the Society, 267 persons connected with the Society, and 345 guests, including 236 ladies, a total of 612, being registered.

Eighteen regular meetings have been held at the Society House, at which the attendance has on several occasions exceeded 100, the average being 85.

Thirty-three formal papers were presented at these meetings, and three meetings were devoted entirely to discussions. In the oral discussion 163 persons took part, and correspondence from 67 was read.

Society Badge.

Total number of old-style badges issued	1 051	
" " " returned	34	
Number of old-style badges now out		1 017
" new " issued to date		317
Total badges issued		1 334

Medals and Prizes.

The Norman Medal for the year terminating August 1st, 1894, was awarded to A. E. Hunt, M. Am. Soc. C. E., for his paper on "A Proposed Method of Testing Structural Steel."

The Rowland Prize for the year terminating August 1st, 1894, was awarded to David L. Barnes, M. Am. Soc. C. E., for his paper on "Distinctive Features and Advantages of American Locomotive Practice."

The Collingwood Prize for Juniors for 1894, being the first award of this prize, was awarded to Morton L. Byers, Jun. Am. Soc. C. E., for his paper on "The Renewal of the Channel Pier of the Cincinnati and Muskingum Valley Railway Bridge over the Scioto River."

Finances.

The reports of the Treasurer, Auditor, and of the Finance Committee are appended.

By order of the Board of Direction.

Chas. Warren Hunt,
Secretary.

REPORT OF THE TREASURER.

In compliance with the provision of the Constitution, the Treasurer presents the following report for the year ending December 31st, 1895:

Balance on hand December 31st, 1894		$6 336 81
Receipts January 1st to December 31st, 1895		50 655 01
Payment of audited vouchers, January 1st to December 31st, 1895	$35 843 72	
Payment on Fifty-seventh Street property	3 000 00	
Balance on hand December 31st, 1895:		
In Union Trust Company	2 562 79	
In Garfield National Bank	14 600 31	
In hands of the Secretary	985 00	
	$56 991 82	$56 991 82

The Society's securities are as follows:

	Par Value.	Cost.
One Chicago and North Western Railway Bond, 5%, coupon	$1 000	$1 035 00
Seven Pennsylvania Railroad General Mortgage Bonds, 6%, registered	7 000	13 556 82
Four Pennsylvania Railroad General Mortgage Bonds, 6%, coupon	4 000	
One Rio Grande Western Railway Bond, 4%, coupon	1 000	773 75
One Pittsburgh and Western Railway Bond, 4%, coupon	1 000	818 75
One Elizabethtown, Lexington and Big Sandy Railroad Bond, 5%, coupon	1 000	1 000 00
One Certificate Croton Aqueduct Stock of the City of New York, 7%, registered	1 000	1 000 00
Ten Shares Stock Consolidated Gas Company of the City of New York	1 000	972 50
Totals	$17 000	$19 156 82

NOTE.—The market value of these securities was recently quoted at $20 560.

During 1895 the Society received 2 623 remittances. Each remittance is individually entered upon the books of the Society, and in such manner that any check, draft, or order can be traced.

All remittances are deposited by the Secretary; and the Society's account is usually immediately credited by the bank with foreign

drafts or orders, on terms favorable to the Society, without waiting for their sale or collection.

All funds withdrawn from the bank or trust company are by checks, which not only require the signature of the Treasurer, but also that of the Secretary.

The Society's securities are kept in its safe deposit box of the Garfield Safe Deposit Company and are subject to joint inspection only; that is, by the Treasurer, accompanied by the Chairman of the Finance Committee or by the Secretary.

Brief Statement Showing the Financial Results and Growth for the Years 1894 and 1895:

Year.	1894.	1895.
Net receipts*	$37 100 35	$39 670 01
Net disbursements †	34 015 62	30 954 89
Surplus to the good	3 084 73	8 715 12
Per Cent. Dividend on Expenditures	9%	28%

It is believed that every Member of the Society may well ponder over this statement, as it points to future possibilities of development, the extent of which would be difficult to estimate. In fact, when considering the financial distress of the last three years, the showing here presented would seem to justify the prediction that as good, if not better, results may be expected in the future.

Respectfully submitted,

John Thomson,

Treasurer.

* Exclusive of balance taken over from past year, of receipts on New Society House and rebate on Engineering Congress expenses.

† Exclusive of investment payments and Engineering Congress expenses.

REPORT OF THE AUDITOR FOR THE

To the Board of Direction of the

Gentlemen,—I have the honor to present the following statement beginning January 1st, 1895.

Receipts.

Balance on hand, December 31st, 1894		$6 336 81
Entrance Fees	$3 715 00	
Current Dues of 1895	22 271 22	
Past Dues, extended from 1894	1 220 24	
Advance Dues of 1896	5 159 88	
Sales of Publications	2 379 93	
New Society Badges	1 107 62	
Introductory Cards to Foreign Societies	6 00	
Certificates of Membership	172 30	
Advertisements	1 952 50	
Interest on Invested Securities	1 130 52	
Compounding Dues	325 00	
Sales of Library Duplicates	170 76	
Rebate on Taxes	4 12	
Proceedings of VIth International Congress on Internal Navigation	35 00	
Miscellaneous	19 92	
		39 670 01
Subscriptions to New Society House		10 985 00
		$56 991 82

YEAR ENDING DECEMBER 31st, 1895.

American Society of Civil Engineers.

of Receipts and Disbursements for the fiscal year of the Society.

Disbursements.

Publications: net	$9 745 03	
Salaries	2 861 64	
		$12 606 67
Current Business, Salaries, Rent of Telephone, Office Expenses, etc.		5 231 89
Finance and Accounts		2 023 00
Postage		2 313 80
Convention and Annual Meeting:		
Convention of 1895	$1 029 32	
Annual Meeting, 1895	811 08	
Annual Meeting, 1896	51 35	
		1 891 75
General Printing and Stationery		1 037 77
Interest on Mortgage:		
5% on $16 000	$400 00	
5% " 11 500	334 37	
		734 37
Taxes		439 30
Library		1 327 83
Janitor		720 00
New Society Badges		1 177 18
House Supplies and Furniture		214 30
Certificates of Membership		85 47
Norman Medal, Rowland and Collingwood Prizes		213 40
Fuel		156 60
Gas		113 85
Water		17 00
Work of Committees		22 00
Insurance		140 70
Box in Safe Deposit		16 00
Repairs and Betterments		86 88
Other Expenditures		385 13
		$30,954 89
On Principal of Mortgage, present Society House		4,500 00
New Society House:		
Purchase of New Property	$3 000 00	
Legal Expenses, Circulars, etc	388 83	
		3 388 83
		$38 843 72
Balance in Garfield National Bank	$14 600 31	
" Trust Company	2 562 79	
" hands of Secretary	985 00	
		18 148 10
		$56 991 82

The compensation paid to each person in the service of the Society during the past year is stated below, and also the several accounts to which these payments have been distributed :

Charles Warren Hunt, Secretary, February 5th to December 31st, 1895		$3 607 15
Charged to Publications	$1 243 80	
Current Business	1 713 35	
Finance and Accounts	272 00	
Convention and Annual Meeting	257 00	
Library	121 00	3 607 15
Francis Collingwood, Secretary, January 1st to February 5th, 1895, and Assistant to February 15th, 1895		$499 99
Charged to Publications	$20 00	
Current Business	399 99	
Finance and Accounts	10 00	
Convention and Annual Meeting	50 00	
Work of Committees	20 00	499 99
Charles Warren Hunt, Assistant Secretary and Librarian, January 1st to February 5th, 1895		$245 53
Charged to Publications	$49 20	
Current Business	31 33	
Finance and Accounts	61 00	
Convention and Annual Meeting	52 00	
Library	52 00	245 53
John Bogart, Treasurer, January 1st to January 16th, 1895.		
Charged to Finance and Accounts		$25 00
John Thomson, Treasurer, January 16th to December 31st, 1895.		
Charged to Finance and Accounts		$575 00
Thomas B. Lee, Auditor and Chief Clerk		$1 800 00
Charged to Publications	$250 00	
Current Business	640 00	
Finance and Accounts	785 00	
Convention and Annual Meeting	125 00	1 800 00
Stancliff B. Downes, Assistant to Secretary, March 1st to April 21st, 1895		$166 66
Charged to Publications	$96 66	
Current Business	25 00	
Finance and Accounts	45 00	166 66

John M. Goodell, Assistant to Secretary, April 29th to December 31st, 1895		$1 210 00
Charged to Publications	$695 00	
Current Business	155 00	
Finance and Accounts	200 00	
Convention and Annual Meeting	45 00	
Library	115 00	1 210 00
M. T. Jefferis, Assistant Librarian		$1 235 00
Charged to Publications	$246 00	
Current Business	46 00	
Convention and Annual Meeting	4 00	
Library	939 00	1 235 00
B. J. Burke, Clerk.		$1 043 25
Charged to Publications	$10 00	
Current Business	1 004 25	
Convention and Annual Meeting	29 00	1 043 25
D. J. Mullen, Stenographer and Typewriter		$795 00
Charged to Publications	$33 00	
Current Business	754 00	
Convention and Annual Meeting	4 00	
Library	2 00	
Work of Committees	2 00	795 00
M. A. Kent, Office Boy		$217 50
Charged to Publications	$3 00	
Current Business	201 50	
Convention and Annual Meeting	1 00	
Library	12 00	217 50
Stenographic Reporters		$262 37
E. G. Crans, Charged to Convention and Annual Meeting	$47 39	
E. G. Crans, Charged to Publications	121 73	
Ernest Atkinson, Charged to Publications	21 00	
R. W. Ryan, Charged to Publications	72 25	262 37
Arthur C. Mander, Janitor.		
Charged to Janitor		$720 00
Total compensation paid		$12 402 45

DISTRIBUTION OF TOTAL COMPENSATION PAID.

Publications	$2 861 64
Current Business	4 970 42
Finance and Accounts	1 973 00
Convention and Annual Meeting	614 39
Library	1 241 00
Work of Committees	22 00
Janitor	720 00
Total	$12 402 45

The funds of the Society are as follows:

FELLOWSHIP FUND:		
Ninety-nine subscriptions to December 31st, 1894		$11 400 00
Premium and accumulated interest December 31st, 1894		1 388 28
Fund on hand December 31st, 1894		$12 788 28
No subscription received during 1895.		
Interest received during 1895		622 07
		$13 410 35
Expended for publications during 1895		622 07
Total amount in this Fund December 31st, 1895		$12 788 28
The present investment of this Fund is:		
Nine Pennsylvania Railroad Bonds, cost	$11 111 82	
One Chicago and North Western Railway Bond, cost	1 035 00	
Cash	641 46	
		$12 788 28
COMPOUNDING FUND:		
Seven payments, at $325	$2 275 00	
Nine payments, at $250	2 250 00	
	$4 525 00	
The present investment of this Fund is:		
One Pennsylvania Railroad General Mortgage Bond, cost 6%	$1 222 50	
Ten shares Consolidated Gas Company of New York	972 50	
One Pittsburgh and Western Railway Bond, 4%, cost	818 75	
One Rio Grande Western Railway Bond, 4%, cost	773 75	
Cash	737 50	
		4 525 00
Carried forward		$17 313 28

Brought forward		$17 313 28
Norman Medal Fund:		
One Certificate Croton Aqueduct Stock, New York City		1 000 00
Rowland Prize Fund:		
One Pennsylvania General Mortgage Bond, 6%, cost		1 222 50
Collingwood Prize Fund:		
One First Mortgage Bond, 5%, Elizabethtown, Lexington and Big Sandy Railroad		1 000 00
General Fund:		
Interest		326 45
New Society House Fund:		
Cash subscriptions received to December 31st, 1895	$10 985 00	
Paid on account of purchase and incidental expenses	3 388 83	
		7 596 17
Total		$28 458 40

Respectfully submitted,

Thomas B. Lee,

Auditor.

REPORT OF THE FINANCE COMMITTEE.

The Committee submits the following comparative statement of receipts and disbursements for the past two years:

	1894.	1895.
Current receipts	$37 100 35*	$39 670 01†
Current expenditures	34 015 62*	30 954 89‡
Excess of receipts over expenditures	$3 084 73	$8 715 12

The Committee also reports that it has performed the duty of auditing all the bills which have been paid during the past year, and has found that each bill has been charged to its proper account.

The Chairman of the Committee has examined the securities in the Safe Deposit Vault and finds them to be as stated in the reports of the Treasurer and Auditor.

In accordance with the provision of the Constitution, the accounts and financial books of the Society have been examined and found correct by an expert accountant.

The report of the Finance Committee for 1894 recommended that as much as possible of the cash balance on hand be invested in proper securities, and the Finance Committee now reports that during the year $4 500 was paid on the principal of the mortgage of the House of the Society, and that a preliminary payment of $3 000 on the purchase-price of the New Society House site was paid out of the current funds during the year.

C. C. Martin, *Chairman.*
Jos. M. Wilson,
J. M. Knap,
Charles Sooysmith,
Foster Crowell,
Committee on Finance.

* Do not include funds received or paid on account of Engineering Congress of 1893.

† Does not include receipts for New Society House Fund amounting to $10 985.

‡ Does not include payment of $4 500 on principal of present Society House, nor payment of $3 388 33 on purchase of new site.

SUBSCRIPTIONS TO NEW SOCIETY HOUSE FUND.

JANUARY 13TH, 1896.

	Amount Subscribed.
Abbot, F. V	$30
Alden, John F	100
Allen, James P	25
"A Member"	75
Andrews, D. M	40
Ashmead, Frank M	25
Atkinson, John B	25
Barnes, D. L	50
Barr, C. C	100
Bates, Onward	50
Bassett, G. B	50
Beckler, E. H	10
Benzenberg, George H	100
Blackstone, T. W	100
Blakeley, G. H	100
Bliss, H. I	25
Boller, A. P	100
Bontecou, D	100
Bonzano, A	50
Boright, William P	10
Boyd, C. R	50
Boynton, G. H	25
Breithaupt, W. H	35
Brinckerhoff, Alexander G	35
Brinckerhoff, H. W	50
Brooks, Fred	100
Buck, L. L	100
Burke, M. D	35
Burr, William H	35
Caples, M. J	25
Carnegie, Andrew	1 000
Carll, D. S	25
Carson, William W	35
Carter, O. M	25
Carter, Shirley	5
Cartwright, Robt	100
Chester, J. N	15
Chibas, E. J	30
Chittenden, S. H	50
Christie, G. B	100
Church, George Earl	100
Clark, E. W	100
Clarke, T. C	$100
Cogswell, W. B	500
Cohen, Mendez	250
Colby, S. K	10
Comstock, Charles W	10
Cooper, Theodore	200
Corthell, E. L	100
Coulson, Ben	10
Craighill, William P	100
Crandall, C. L	25
Crehore, W. W	10
Cunningham, D. W	35
Curtis, F. S	300
Curtis, W. W	25
Davis, Arthur L	10
Davis, Joseph P	300
Davison, George S	25
De Courcy, Bolton W	60
Deyo, S. L. F	100
Doane, Thomas	35
Erlandsen, O	50
Evans, M. E	5
Evening Post Job Office	250
Fanning, J. T	50
Fink, Albert	500
FitzGerald, Desmond	200
FitzGerald, J. Leland	50
Fleming, Sanford	50
Ford, P. D	35
Fox, Sir Douglas	50
Francis, James	50
Freeman, F. L	50
Freeman, John R	50
French, Alexis H	50
Frost, George H	35
Fteley, A	200
Fuller, W. B	25
Gardner, Martin L	25
Garrison, T. Lynwood	100
Gates, C. L	25
Gates, H. D	40
Goad, Charles E	50

	Amount Subscribed.
Goodell, John M	$100
Graham, Charles H	50
Grant, J. Herbert	70
Grant, T. H.	35
Gray, Edw. J.	35
Green, Bernard R	100
Griswold, F. L	100
Haines, H. S	50
Harrod, B. M	50
Haswell, Charles H	25
Hendricks, V. K	15
Herbert, Arthur P	25
Hering, Rudolph	50
Hill, Albert B	50
Hill, John E	10
Hitchcock, F. C	25
Hopkins, A. L	10
Hopkins, Charles C	50
House, T. E	15
Houston, J. J. L	25
Hoyt, William E	25
Hudson, John R	25
Hunt, Charles Warren	100
Hussey, C. G	50
Ingram, E. L	10
Irwin, J. C	10
Jacoby, H. S	20
Jamieson, J. T	20
Janney, W. D	25
Jarrett, Edwin S	25
Jaques, W. H	15
Johnson, J. B	25
Johnston, A. W	35
Jones, Washington	100
Jordan, E. C	15
Juengst, H. F	40
Just, George A	100
Keith, Herbert C	10
Kelley, H. G	35
Knap, J. M	100
Knight, W. H	35
Kuichling, E	30
Landreth, W. B	35
Lederle, George L	200

	Amount Subscribed.
Lesley, R. W	$100
Leverich, G	100
Lewinson, M	100
Lewis, James F	25
Lovett, Thomas D	100
Lowe, Jesse	100
McCulloh, Walter	25
Macfarlane, James	25
Martin, C. C	100
Maurice, C. S	35
Maxim, Hiram H	35
Mayer, Joseph	25
Melvin, David N	100
Metcalf, William	300
Miller, Silvanus	100
Modjeski, Ralph	50
Montony, L. G	25
Moore, William Harley	15
Morison, George S.	500
Morris, C. J. A	35
Morris, Gouverneur	35
Morris, S. F	25
Mosscrop, Alfred M	10
Myers, John H	10
Nettleton, George H	100
New York Car Wheel Works	25
Nicholson, G. B	100
Nicholson, G. L	10
Noble, Alfred	100
North, Edw. P	100
Ockerson, J. A	25
Olcott, E. E	25
Olney, Lafayette	25
Olney, R. B	20
O'Rourke, John F	100
Paine, Charles	100
Parsons, William Barclay	150
Perkins, C. E	100
Poland, W. B	10
Pomeroy, L. R	100
Potter, Dwight	20
Porter, H. H	100
Post, Andrew J	25
Post, Walter A	25

	Amount Subscribed.
Potter, Alexander M.	$100
Prince, Edward	100
Purdon, C. D	25
Rafter, George W.	50
Randolph, L. S	25
Reece, Benjamin	50
Rice, George S.	25
Richardson, Henry B	25
Ricketts, Palmer C	100
Roberts, William	100
Robinson, A. A.	100
Rodd, Thomas	50
Roullier, G. A.	35
Rosenzweig, Alfred	250
Sample, John H.	50
Sawyer, Edward	100
Seaman, H. B	100
Scarborough, F. W	100
Shailer, R. A	50
Shaler, Ira A	50
Sherman, Charles W	10
Sherrerd, M. R	10
Smith, H. S. S,	25
Smith, T. Guilford	100
Snow, J. P	25
Sooysmith, Charles	500
Stauffer, D. McN	50
Stearns, Frederick P	$50
Steward, Herbert	100
Storrow, Charles S	50
Strobel, C. L	50
Sykes, Martin L	100
Taylor, Charles F	10
Taylor, Lucien A	200
Temple, R. H	35
Thomson, John	200
Thorndike, John L	250
Tomkins, Calvin	50
Trautwine, John C., Jr.	50
Trotter, Alfred W	100
Van Horne, John G	100
Veazie, J	35
Voorhees, Theodore	100
Wells, Charles E	35
Wetherill, W. C	25
Wheeler, S. S	50
Whinery, S	100
Whitcomb, H. D	35
Wiley, A. J	50
Wiley, Wm. H	100
Williamson, S. B	40
Williamson, W. G	5
Worcester, J. R	10
Yeatman, M. E	10

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

			Date of Membership.
CHASE, CHARLES FRANCIS	75 Westminster St., Providence, R. I.		Jan. 1, 1896
DAVIS, CHARLES HENRY	99 Cedar St., New York City		Dec. 4, 1895
DEL MONTE, EMILIO	Apartado No. 496, Havana, Cuba		Dec. 4, 1895
DE TEIVE E ARGÔLLA, MIGUEL	Alagoinhas, Bahia, Brazil		Oct. 2, 1895
GEMMELL, ROBERT CAMPBELL	221 Second East St., Salt Lake City, Utah	Assoc. M. M.	Oct. 5, 1892 Dec. 4, 1895
GIFFORD, GEORGE EDWIN	Eastern Representative and Engineer, King Bridge Co., New York City	Assoc. M. M.	Oct. 7, 1891 Jan. 1, 1896
MCCARTY, RICHARD JUSTIN	1624 Jefferson St., Kansas City, Mo.		Dec. 4, 1895

ASSOCIATE MEMBERS.

KNOWLES, MORRIS	With Metropolitan Water Board, Boston, Mass.		Jan. 1, 1896
MESA, ANTONIO ESTEBAN	58 W. 129th St., New York City		Jan. 1, 1896
RAPP, JOHN VAN BUSKIRK	45 Broadway, New York City		Feb. 7, 1894
STORROW, SAMUEL	Civil Engineer, North Yakima, Wash	J. Assoc. M.	Sept. 10, 1891 Oct. 2, 1895
TUSKA, GUSTAVE ROBITSCHER	Consulting Engr., and Instructor in Engineering, School of Mines, Columbia College, New York City	J. Assoc. M.	Mar. 6, 1894 Jan. 1, 1896
WOLVERTON, IRVING MASON	Chief Engr., New Columbus Bridge Co., Columbus, Ohio.		Dec. 4, 1895

CHANGES AND CORRECTIONS.

MEMBERS.

ALDRICH, T. H	Birmingham, Ala.
AMBROSE, W. C	Res. Engr., S. P. Co., Kern, Pa.
AMWEG, F. J	700 Hale Bldg., Philadelphia, Pa.

BACOT, W. S	1 Broadway, New York City.
BALDWIN, F. H	Engr. Pijepscot Paper Co., Brunswick, Me.
BALDWIN, THOMAS W.	Boothbay Harbor, Me.
BEAHAN, WILLARD	Pres. Anderson & Barr Clay Co., Streator, Ill.
BECKLER, E. H.	1339 Wilton Ave., Chicago, Ill.
BENYAURD, W. H. H	Drawer 19, St. Augustine, Fla.
BILLIN, CHARLES E	1534 Marquette Bldg., Chicago, Ill.
BISSELL, F. E.	Chief Engr., Ft. Worth and Denver City Ry., Fort Worth, Tex.
BOGART, JAMES P.	291 Fairfield Ave., Bridgeport, Conn.
BRADLEY, WILLIAM H	53 State St., Boston, Mass.
BRECKENRIDGE, CABELL.	Hunnicutt, Morgan Co., Tenn.
BROWN, WILLIAM H.	Chief Engr., Pa. R. R. Co., Broad St. Station, Philadelphia, Pa.
BURBANK, GEORGE B.	15 Wall St., New York City.
BUSH, H. D	565 Main St., Springfield, Mass.
CRAIG, C. M	Chief Engr., Southern Pine Co. of Georgia, Offerman, Ga.
CRAVEN, ALFRED	Div. Engineer, Aqueduct Commission, Kingsbridge, N. Y.
CRAWFORD, WILLIAM	Victoria Chambers, Ottawa, Canada.
CUNNINGHAM, A. C.	51 State St., Albany, N. Y.
DENNIS, W. F	415 Main St., Cincinnati, Ohio.
FAIRLEIGH, J. A.	349A Quincy St., Brooklyn, N. Y.
FELTON, S. M	Pres. and Receiver, C., N. O. & S. P. Ry. Co., Odd Fellows Bldg., Cincinnati, Ohio.
FULLER, W. B.	3 Mt. Vernon St., Boston, Mass.
GATCHELL, G. S.	Mgr. Buffalo Elevating Co., 67 Board of Trade, Buffalo, N. Y.
GRANT, WILLIAM H	46 Broad Ave., Sing Sing, N. Y.
GUTHRIE, E. B	Asst. Chief Engr., Buffalo, N. Y.
HAGUE, C. A	39 Cortlandt St., New York City.
HARLOW, J. H.	Chief Engr., Susquehanna Electric Power Co., Conowingo, Cecil Co., Md.
HEALD, S. C.	48 Congress St., Boston, Mass.
HERRICK, H. A	36 Prospect St., Manchester, N. H.
HISLOP, JOHN	1012 18th St., Denver, Colo.
HITCHCOCK, F. C.	Care of George S. Good Co., Lock Haven, Pa.
HORTON, H. E.	Pres., Chicago Bridge & Iron Co., 10,206 Longwood Ave., Chicago, Ill.
HOWARD, F. B.	175 Griswold St., Detroit, Mich.
HOWE, W. B. W.	Kingsford, Fla.
HUNT, A. E.	Pres., The Pittsburg Reduction Co., 701 Ferguson Bldg., Pittsburg, Pa.
HUNT, R. W.	1137 The Rookery, Chicago, Ill.
HUTCHINSON, G. H.	With Brown Hoisting and Conveying Machine Co., Cleveland, Ohio.
IVES, E. B.	917 Betz Bldg., Philadelphia, Pa.

Jackman, H. H. .... Engr. Chg. of Surveys, Harbor Dept., Bureau of Engineering, Chicago, Ill.

King, F. P. .... West Palindale P. O., Los Angeles Co., Cal.

King, P. S .... P. O. Box 162, Waltham, Mass.

Kingsley, M. W. .... Supt. of Water-Works, Cleveland, Ohio.

Kinney, E. C .... Gen. Mgr. West Gallatin Irrig. Co., Manhattan, Montana.

Knight, W. H. .... General Electric Co., New York City.

Landor, E. J .... Pres. and Chf. Engr. Wrought Iron Bridge Co., 259 Prospect St., Canton, Ohio.

Lassig, M .... Pres. Lassig Bridge and Iron Works, 707 The Rookery, Chicago, Ill.

Leonard, H. R. .... 510 Harrison Bldg., Philadelphia, Pa.

Lucas, D. J. .... 1929 Columbia Ave., Philadelphia, Pa.

MacNaughton, James .... Pres. and Treas. MacIntyre Iron Co., 86 State St., Albany, N. Y.

Mann, G. E. .... Chf. Engr. Grade Crossing Comm., 4 Municipal Bldg., Buffalo, N. Y.

Mansfield, M. W .... Supt. Pa. Co., I. & V. Div., Indianapolis, Ind.

Marstrand, O. J. .... 397 7th St., Brooklyn, N. Y.

Martin, C. C .... Chf. Engr. and Supt. N. Y. & B. Bridge, 194 Berkeley Place, Brooklyn, N. Y.

Masten, C. S .... Chf. Engr. M. & P. & Salt River Val. R. R., Phœnix, Arizona.

May, De Courcy .... P. O. Box 173, Baltimore, Md.

McKeown, Thomas .... 3135 Main St., Buffalo, N. Y.

Menocal, A. G. .... Navy Yard, Brooklyn, N. Y.

Merrill, W. F .... 2d Vice-Pres. Erie R. R., 21 Cortlandt St., New York City.

Minot, S. L .... 3 Somerset St., Boston, Mass.

Morrill, G. S. .... Div. Engr. N. Y., N. H. & H. R. R., Boston Mass.

Myers, Charles H. .... Engr. of Sewer Construction, 29 Municipal Bldg., Brooklyn, N. Y.

Nichols, L. A. .... 306 Boyce Bldg., 114 Dearborn St., Chicago, Ill.

Northrop, H. F. .... City Engineer, Traverse City, Mich.

Paine, A. B .... Hotel Medberg, Ballston Spa, N. Y.

Paret, M. P. .... Res. Engr. Arkansas Const. Co., Sallisaw, Ind. Ter.

Peary, R. E. .... Civil Engr. U. S. Navy, U. S. Navy Yard, Brooklyn, N. Y.

Pierce, Henry .... Engr. M. of W., C. & O. Ry., Huntington, W. Va.

Prevost, S. M. .... Gen. Mgr. Pa. R. R., Broad St. Station, Philadelphia, Pa.

Reece, Benjamin .... Engr. The Q. & C. Co., 705 Western Union Bldg., Chicago, Ill.

RICE, GEORGE S.	95 Milk St., Boston, Mass.
RICHARDS, J. T.	Engr. M. of W., P. R. R. Co., Broad St. Station, Philadelphia, Pa.
RICHARDSON, B. FRANK.	2217 Federal St., Philadelphia, Pa.
RIFFLE, A. S.	Portland, Ore.
ROBINSON, S. W.	1353 Highland St., Columbus, Ohio.
ROWE, R. D.	87 74th St., Chicago, Ill.
SAMPLE, J. H.	Gen. Supt. Northern Ohio Ry., Akron, Ohio.
SCHAUB, J. W.	Chf. Engr. and Mgr. Hamilton Bridge Works, Co., Ltd., Hamilton, Ontario, Canada.
SCHNEIDER, C. C.	Chf. Engr. Bridge and Const. Dept., Pencoyd Iron Works, Pencoyd, Pa.
SKILTON, GEORGE S.	Asst. Engr. Brooklyn City Works Dept., Rockville Center, Queens Co., N. Y.
SEARS, ALFRED F.	37 Lafayette Ave., Brooklyn, N. Y.
SEWALL, J. S.	St. Anthony Park, St. Paul, Minn.
SMITH, F. H.	Fidelity Bldg., Baltimore, Md.
SMITH, WILLIAM SOOY.	Stock Exchange Building, Chicago, Ill.
STEWART, J. M.	Asst. Engr. Dept. of Docks, foot of West 50th St., New York City.
THOMSON, G. H.	51 East 44th St., New York City.
TIMONOFF, V. E.	Prof. Institute of Ways of Communication, First Rota No. 7, Log. 163, St. Petersburg, Russia.
TURNER, NATHANIEL.	66 Calle de San Francisco, Monterey, Mexico.
URQUHART, G. C.	Asst. Engr. P. C. C. & St. L. Ry. Co., 1003 Penn. Ave., Pittsburgh, Pa.
VANDERPOOL, EUGENE.	Newark, N. J.
VAN SANT, R. L.	609 Commercial Bldg., St. Louis, Mo.
VAUGHN, G. W.	Leavenworth, Kan.
WAINWRIGHT, JONATHAN.	Conestoga Bldg., Pittsburgh, Pa.
WARD, JOHN F.	45 Broadway, New York City.
WASHBURN, F. S.	"Gerard" 125 West 44th St., New York City.
WENTWORTH, W. H.	Pres. Las Morias Mining Co., Monterey, Nuevo Leon, Mexico.
WHITNEY, F. O.	Office of Street Commissioner, 27 Old Court House, Boston, Mass.

ASSOCIATE MEMBERS.

BAIER, JULIUS	Room J, Turner Bldg., St. Louis, Mo.
BELKNAP, W. E.	Asst. Engr., Dept. City Works, 49 Municipal Bldg., Brooklyn, N. Y.
BRYAN, KENNERLY	156 Fifth Ave., New York City.
BUCK, R. S	Niagara Falls, N. Y.
CAMPBELL, A. J.	Broad Street Ave., London, E. C., England.
CARLL, D. S.	Chief Engr. and Supt. Capitol Traction Co., Washington, D. C.
CONNOR, E. H.	Res. Engr., Rock Island Bridge, Rock Island, Ill.

Creuzbaur, R. W.............Dean & Creuzbaur, Guatemala City, Guatemala.
Dunn, E. C.................City Engr., Alexandria, Va.
Elliott, J. S................1820 Jefferson Place, Washington, D. C.
Eldridge, G. M..............Supt. Defiance Water Co., Ohio.
Ewing, W. B.................City Engineer, La Grange, Ill.
Frease, Harry...............Chief Engr., Canton & East Liverpool Ry. Co., Canton, Ohio.
Gray, Edward, Jr............City Hall, Richmond, Va.
Harahan, W. J...............Supt. Ill. Cent. R. R., Freeport, Ill.
Healy, J. F.................Supt. Mt. Clove Coal Co., Mt. Clove, W. Va.
Hill, E. A..................Care of Commissioner of Patents, Washington, D. C.
Himes, A. J.................Res. Engr., East. Div., N. Y. State Canals, 297 Madison Ave., Albany, N. Y.
Janney, W. D................Pres. Wells Branch Coal Co., Ceredo, Wayne Co., W. Va.
Riggs, H. E.................424 The Nasby, Toledo, Ohio.
Stenger, E..................4012 Nicholas St., Omaha, Neb.
Treadwell, Lee..............Kansas City, Mo.
Van Cleve, A. H.............Office Asst. Cataract Const. Co., Echota, Niagara Falls, N. Y.

ASSOCIATES.

Burnham, George, Jr.........500 N. Broad St., Philadelphia, Pa.
Clark, L. V., Jr............Mgr. Lawrence Cement Co., Harrison Bldg., Philadelphia, Pa.
Davis, J. Woodbridge........417 Madison Ave., New York City.
King, H. W..................Vice-Prest. The King Bridge Co., Cleveland, Ohio.
Lewis, J. F.................1328 Monadnock Block, Chicago, Ill.
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Annual Report of the U. S. National Museum for the year ending June 30th, 1893.
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Timber; an Elementary Discussion of the Characteristics and Properties of Wood.

From U. S. Geological Survey:
Sixty-seven Maps of the U. S. Geological Survey.

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Report of the Surgeon-General, U. S. Navy, September 11th, 1895.

From U. S. War Department, Chief of Engineers:
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From Welton & Bonnett, Waterbury, Conn.;
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1896. JANUARY, No. 1.

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PAPERS.

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CONTENTS:

FLOW OF WATER IN 48-IN. PIPES.

By DESMOND FITZGERALD, M. Am. Soc. C. E.

TO BE PRESENTED FEBRUARY 5TH, 1896.

The experiments here described were made in 1894–95 on the Rosemary inverted siphon, a part of the Sudbury Aqueduct supplying the city of Boston with water. As the pipes had been in use sixteen years it was thought that it would be of value to determine how much their capacity had been diminished by the increased friction due to the incrustation of the interior surfaces. A series of experiments was planned in 1893, but it was not until September, 1894, that all the preparations were completed, the weirs and piezometers erected, and the experiments begun. Many delays and difficulties were encountered from the fact that much of the work had to be done inside the aqueduct, which was in regular service, so that the flow could be stopped only for short intervals.

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

Description of the Siphon.—The Sudbury River Aqueduct is 17.4 miles long, and for the greater part of its length it is 7 ft. 8 ins. high and 9 ft. wide. At a distance of 11.7 miles from its head at Framingham the water is carried across the valley of Rosemary Brook through two 48-in. cast-iron mains, 1 800 ft. long, laid side by side on a straight line in plan, and descending gradually into the valley to a grade about 48 ft. below the bottom of the aqueduct, forming an inverted siphon (see profile, Fig. 1). The changes of gradient are made with vertical curves. The ends of the pipes are furnished with gate-chambers covered with substantial masonry buildings. The pipes were laid in 1877, and were first put into service in 1878; they were of the usual hub and spigot form, cast in lengths of 12 ft. The pipes were coated with Dr. Angus Smith's coal-tar preparation. The joints were well made. Two diameters were measured at each of 37 stations; the mean diameter thus obtained was 3.998 ft., taken as 4 ft. An attempt was made to figure the diameter by filling the pipe with water which was first passed over a small standard weir. It was found impossible to arrive at as correct a result by this method as by measurements of the pipe.

Before beginning the experiments photographs were made by flash light of the interior of the pipes showing the tuberculated surfaces. Two of these photographs are reproduced on Plate I, Figs. 1 and 2. It was estimated that the tubercles covered nearly one-third of the interior surfaces, the bottom being more thickly incrusted with them, while the tops and sides of the pipes were cleaner.

Scheme of Experiments.—The losses of head were measured as near the extremities of the pipe as it was wise to place the piezometers, and in two ways, first, by a set of piezometers screwed into the pipes, and second, by tube gauges placed lengthwise on the bottom of the pipes and connecting with lead pipes extending out of the open ends to gauge chambers. The former method was more elaborately carried out and was considered the principal one. The latter had been adopted by F. P. Stearns, M. Am. Soc. C. E., in his experiments at the same place, and by using it in addition it was expected that a valuable check on the results would be secured.

It was found impossible to arrange a weir measurement in the aqueduct near the siphon which would admit of a greater velocity than about 3.7 ft. per second through one pipe. It was therefore determined

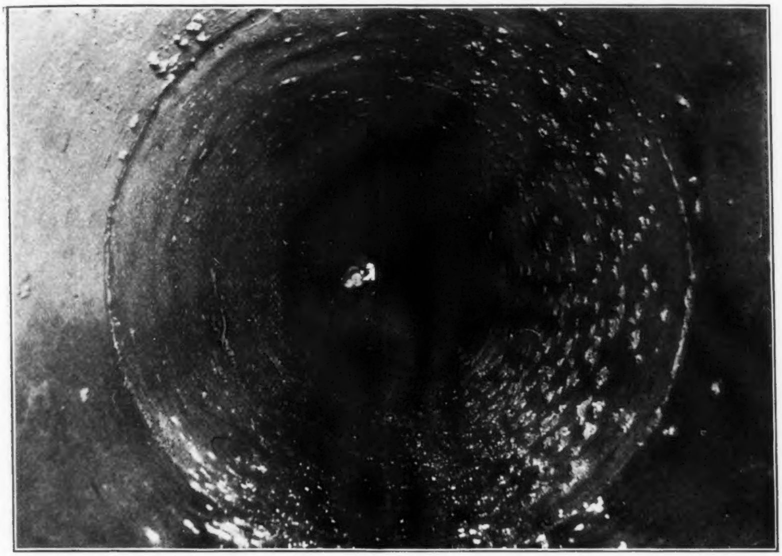


FIG. 1.

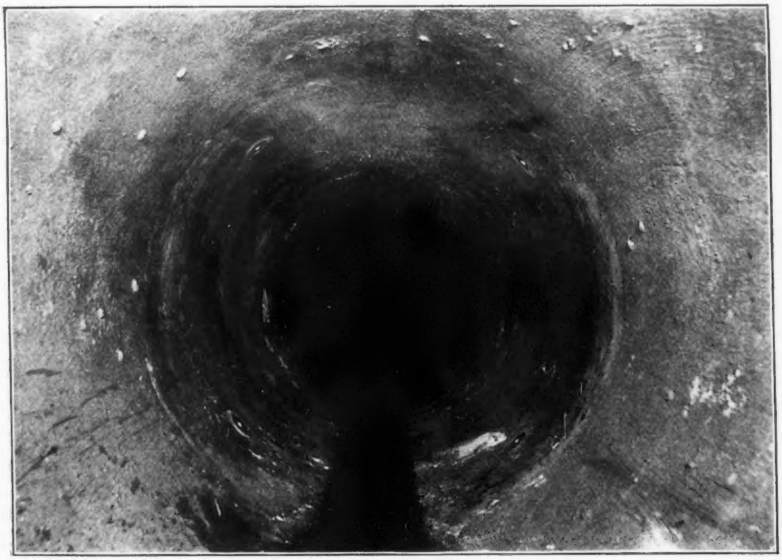
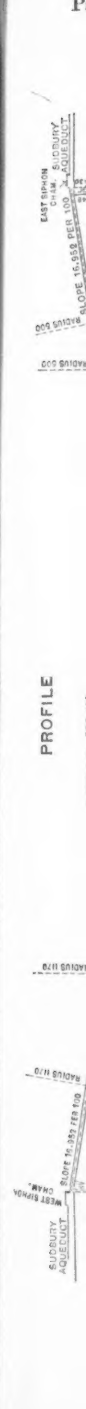
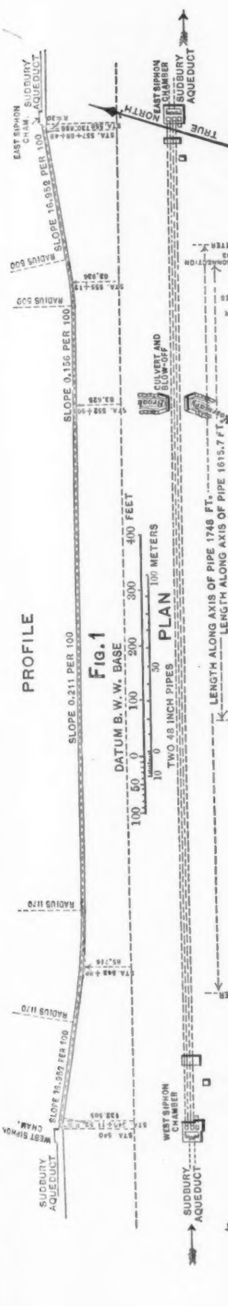


FIG. 2.


PROFILE
EAST SIPHON CHAM.
SUDBURY AQUEDUCT
SLOPE 16.952 PER 100
RADIUS 600
RADIUS 1170
WEST SIPHON CHAM.
SUDBURY AQUEDUCT



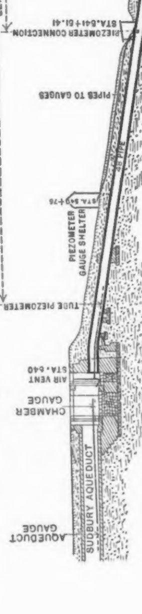


FIG. 2. WEST SIPHON CHAMBER

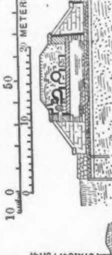


FIG. 3. CROSS-SECTION SHOWING CULVERT AND BLOW-OFF STA. 552+90

FIG. 4. EAST SIPHON CHAMBER

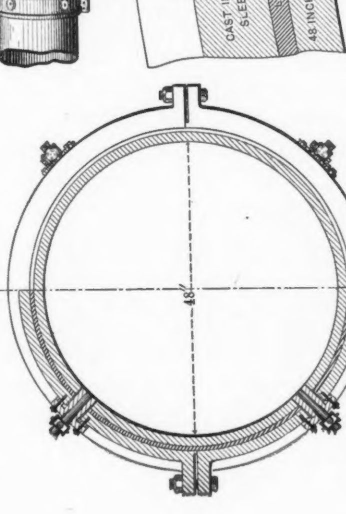


FIG. 5. HALF SECTION AND HALF-ELEVATION OF SLEEVE

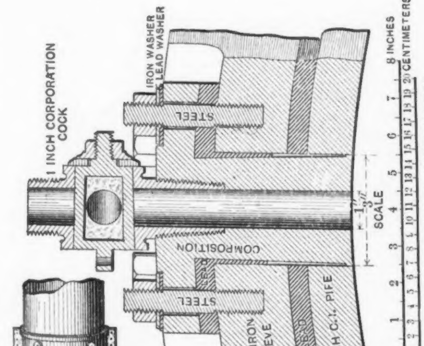


FIG. 6. SECTION THROUGH PIEZOMETER

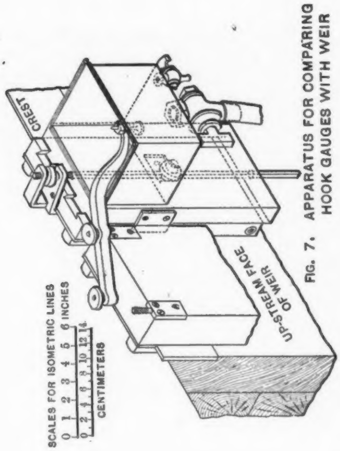


FIG. 7. APPARATUS FOR COMPARING HOOK GAUGES WITH WEIR

to measure the flow up to this velocity through each pipe in turn; then to scrape all the tubercles from one pipe and experiment again upon the pipe as cleaned; then to erect two weirs at the terminus of the aqueduct at Chestnut Hill Reservoir about 5.3 miles distant, and connect the weir measurement at the siphon with the weir measurement at the terminal chamber by means of an extended series of observations which would give a comparison between them at different rates of flow up to about 45 cu. ft. per second. The siphon weir was then to be taken out in order to secure as high a velocity as possible in one pipe, the discharge being measured by means of the weirs at the terminal chamber.

This general programme was carried out. The new weirs of course held back the water in the aqueduct, and it required a careful adjustment of the hydraulic gradient to arrange for the desired flow; but the coefficient of friction of the aqueduct was well known, as was the approximate coefficient of the pipes after the first series of experiments had been completed. Observations were begun on September 4th, 1894, upon the south pipe, tuberculated, and were continued on this pipe at various times up to and including October 6th. Velocities ranged from about 3.5 ft. per second to rather less than 0.5 ft. per second, and the experiments were generally repeated several times for each velocity. On October 18th the flow was changed to the north pipe, tuberculated, and this pipe was experimented upon with the same series of velocities as the south pipe.

The north pipe was cleaned November 12th, 13th, 14th and 15th by removing the tubercles completely from the interior. A photograph was then taken of the surface as cleaned (see Plate II). It was found possible to remove tubercles without injuring materially the original coating underneath them, and, as will be seen by an examination of Plate II, the original condition of the pipe was practically restored. The tubercles generally had central points or very small spots of attachment to the iron of the pipes. At these points the coating was lacking of course; but around them the tubercles spread over the surface of the coating, which remained in fair condition beneath. The original capacity of the pipe to pass water under a given head was nearly restored, the increase amounting to 30% at ordinary velocities. This was accomplished at small expense. There were 22 619 sq. ft. of surface scraped, swept and cleaned, with 57 days' labor,

PLATE II.
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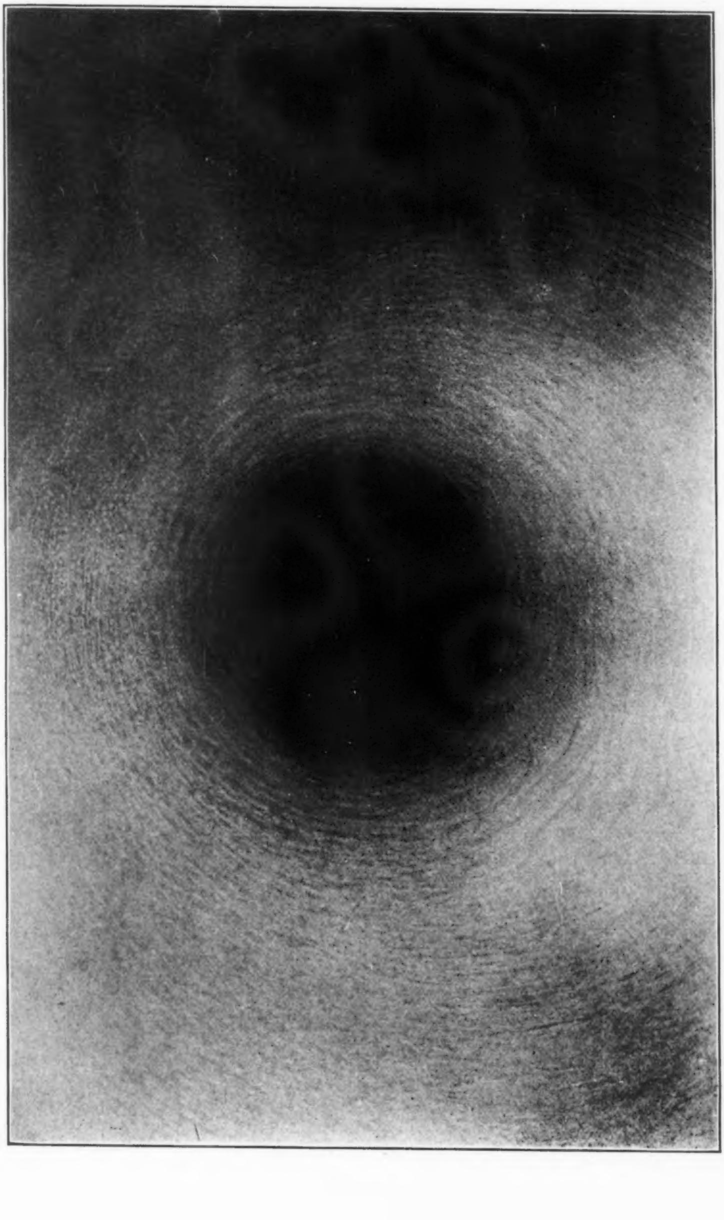
JANUARY, 1896.
FITZGERALD ON FLOW OF WATER IN PIPES.



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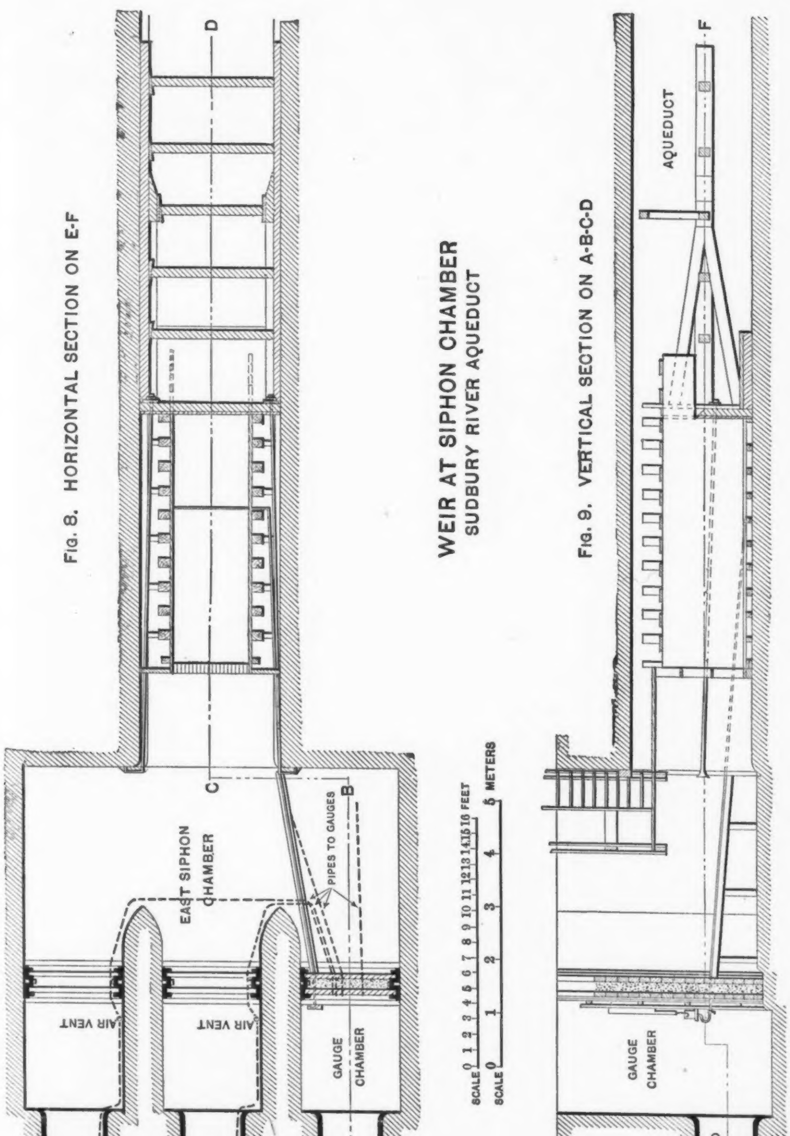


FIG. 8. HORIZONTAL SECTION ON E-F

WEIR AT SIPHON CHAMBER
SUDBURY RIVER AQUEDUCT

FIG. 9. VERTICAL SECTION ON A-B-C-D

the space cleaned per man per day being 396 sq. ft. of surface, or about 32 lin. ft. of pipe. The labor was subdivided as follows: 32 days scraping tubercles; 21 days sweeping and washing the pipe, and 4 days wheeling material. The scraping for a width of 2 ft. at the bottom was done with old round-pointed iron shovels; for the rest of the pipe with wooden scrapers made of oak, great care being taken not to disturb the tar coating. About two cart-loads of tubercles were taken out, beside what was flushed out of the blow-offs.

Beginning on November 30th, the experiments were continued on the cleaned north pipe at velocities ranging from 3.6 to less than 0.5 ft. per second. Early in November the terminal chamber weirs were erected and compared with the siphon weir (see Table No. 5), after which the siphon weir was removed and experiments were resumed on the cleaned north pipe, and extended to velocities of 7.25 ft. per second, which was the largest amount of water that it was practicable to pass through one pipe. On January 23d, 1895, the experiments at high velocities on the south pipe, tuberculated, were completed, but it was found practicable only to carry these velocities to 5.5 ft. per second.

The piezometer observations are recorded in Tables Nos. 3 and 4, the former including those piezometers only which were screwed into the sides of the pipes, and the latter the tube piezometers lying on the bottom of the pipes.

Measuring Apparatus at the Siphon Chambers.—The siphon chambers, as may be seen in Figs. 2, 4, 8 and 9, are built so that a third 48-in. pipe can be added in the future. It was determined to use the compartments provided for this third pipe as gauge chambers. They were made perfectly tight by means of double sets of stop-planks with puddle filling. The tube gauges were led into these compartments, and in the case of the east siphon chamber a pipe from the weir was carried into the same compartment to a small gauging box to which a hook-gauge was adjusted. Great care was taken to have these pipes rise by uniform grades to their gauges, and, where a summit was unavoidable, to put in a vent pipe carried above the water-level. In this way serious errors, which are often made in the readings of piezometers and weir gauges, due to collections of air, were avoided. The lengths of pipe under observation were 1 748.1 ft.

of the north pipe and 1 747.96 ft. of the south pipe, those being the distances, referred to the axes of the pipes, between the middle points of the brass tubes.

Piezometers.—The piezometers that were screwed into the pipe from the outside were arranged in the following manner: A point was selected at the west end of the siphon sufficiently remote from the entrance of the pipe to allow the water to attain regular motion. This

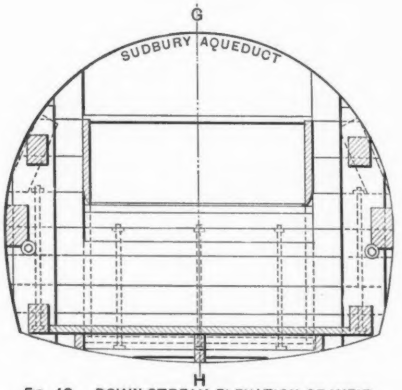


FIG. 10. DOWN-STREAM ELEVATION OF WEIR

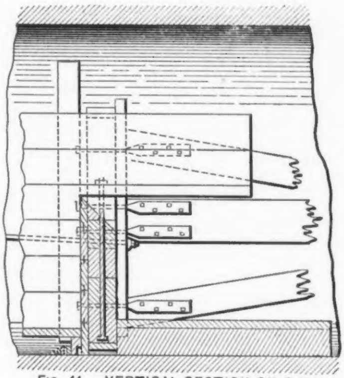


FIG. 11. VERTICAL SECTION ON G H

SCALE 0 1 2 3 4 5 6 FEET

SCALE 0 1 2 METERS

DETAILS OF
WEIR AT SIPHON CHAMBER

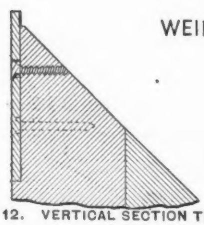


FIG. 12. VERTICAL SECTION THROUGH CREST

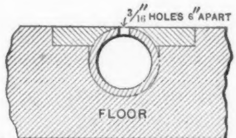


FIG. 13. BRASS PIPE 6 FT. BACK FROM CREST

SCALE 0 1 2 3 4 INCHES

SCALE 0 1 2 3 4 5 6 7 8 9 10 CENTIMETERS

was 151.41 ft. from the upper end of the pipe. The east piezometers were inserted at 38.07 ft. from the lower end. The distance between these points, measured along the axis of the pipe, was 1 615.7 ft. Four openings were made in each pipe at each of these points (sixteen holes in all), and as the welfare of the city depended upon the maintenance of the flow, sleeves were first put around the pipes where the

holes were to be made. A tool was devised by which 3-in. holes were bored through the sleeve and pipe at the four points of section, as shown in Fig. 5.

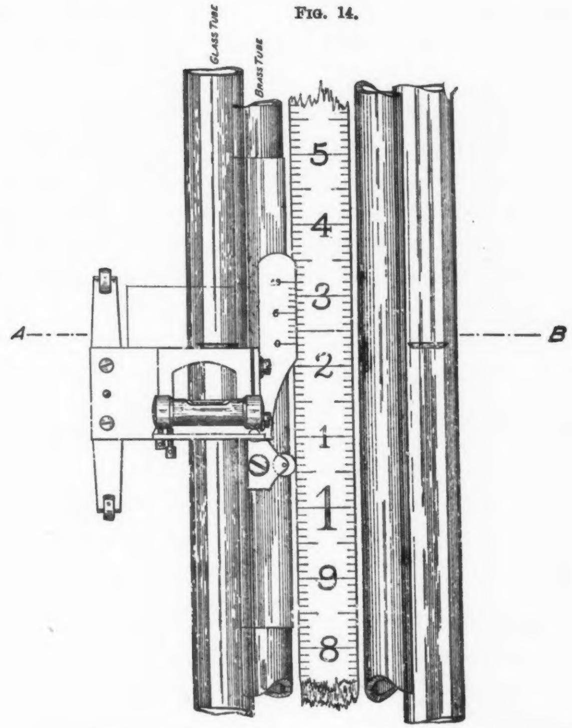
Into these holes piezometers were inserted and secured, so that the axes of the tubes were at right angles to the direction of the flow. These connections were accurately finished to the curvature of the pipe. They can be distinguished in Plate I, Fig. 2. The incrustation was removed from the interior of the pipe around the place of attachment, so that this portion of the surface was smooth. Into the outsides of these piezometer connections 1-in. corporation cocks were fitted to which lead pipes were soldered. These lead pipes from opposite sides of the 48-in. pipes were connected in pairs and then carried to the gauges, which were conveniently located for reading the extreme variations of head, and were provided with shelters for the observers. Care was taken to have no summits or depressions on these pipes.

Gauges.—Each shelter contained a gauge arranged as shown in Figs. 14 and 15. This gauge was set for reading the two glass tubes containing the water columns, which were about 1 in. in internal diameter. These glass tubes could be connected with the lead pipes from either of the 48-in. pipes as desired. Behind the glass tubes were brass pipes for the verniers to slide upon. The scales were specially graduated by Gurley, and the verniers were made by Buff & Berger. The readings were recorded to thousandths of a foot. The lead pipes were furnished with stop and waste cocks, both at the connections with the 48-in. pipes and at the bottoms of the gauges, so that the observers could frequently test the water columns, to make sure that they were free from obstructions.

Weir at the Siphon.—The general arrangement of the weir at the siphon with details is shown in Figs. 8, 9, 10, 11, 12 and 13. It was 5 ft. long, 3.04 ft. high and approached by a channel 16 ft. long. It was securely built into the aqueduct and was tied by iron rods to the gate-chamber, so that it could not move, and was braced with heavy timbers on the down-stream side. It was provided with a screen to smooth the approach of the water to the weir. The head was read at a point 6 ft. above the crest by means of a brass tube laid across the channel of approach, laid flush with the bottom and

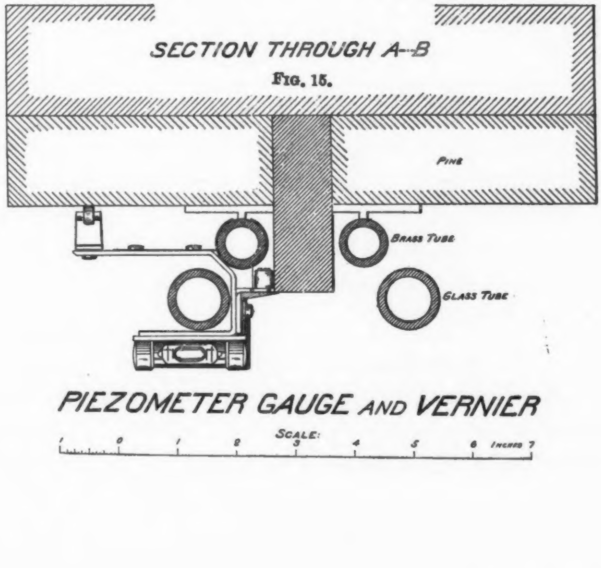
ELEVATION

Fig. 14.



SECTION THROUGH A–B

Fig. 15.



PIEZOMETER GAUGE AND VERNIER

pierced with $\frac{3}{16}$-in. holes 6 ins. apart, smoothly finished, and connected with the measuring chamber as already described. A blow-off cock at the gauge, which was frequently opened, prevented accumulations of air.

Careful measurements of the weir were made before each experiment, and changes in form, due to swelling or distortion, were noted. This is necessary in the case of a wooden weir, for, even with the best of workmanship, changes are constantly occurring. Fig. 7 shows an improved apparatus for comparing the level of the weir with the hook gauge. The method is the same as that used by Messrs. Fteley and Stearns in their weir experiments, but the apparatus has been made more convenient by the special arrangements shown. The hook is first adjusted by a delicate spirit level to the level of the crest, the sliding tin box is then brought up under the hook, the cock opened and an approximate adjustment made of the water surface to the level of the hook, which is made complete by a slow-motion screw; the elevation can then be read at once at the hook gauge at the other end of the pipe without waiting for wave motions to subside.

Weirs at the Terminal Gate Chamber.—The Sudbury Aqueduct terminates at Chestnut Hill Reservoir with a large stone chamber provided with five compartments controlled by gates and stop-planks, and conducting the water into the reservoir or into other connections. The two west compartments connect with the reservoir. In these, two weirs were built, and the other connections were dammed off by clay dams made perfectly tight. The west weir had a length of 5.84 ft., and the east weir 6.32 ft. They were both at the same level and 3.65 ft. high. The position of these weirs with reference to the flow in the aqueduct was peculiar. But satisfactory results were obtained by extensive screening and the use of a liberal amount of brush compactly placed, as shown in Figs. 16 and 17. The sheets of water passing over these weirs, with the largest quantities flowing, were not perfectly smooth, but very nearly so.

Comparative Observations between the Siphon and Terminal Chamber Weirs.—The flow in the aqueduct was adjusted at 3 o'clock P. M. for the amount of water required, and at 10 o'clock the next morning, when the water was flowing uniformly throughout the length of the aque-

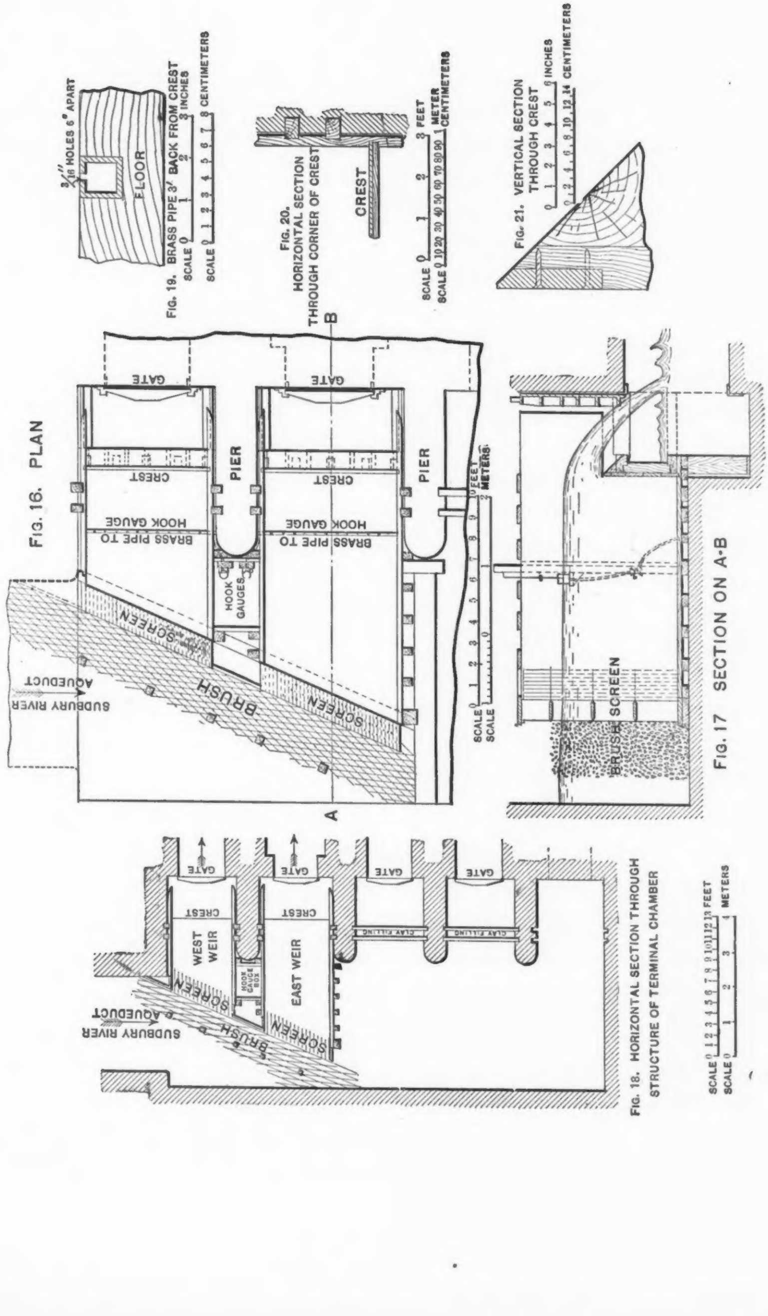


FIG. 16. PLAN

FIG. 17 SECTION ON A-B

FIG. 18. HORIZONTAL SECTION THROUGH STRUCTURE OF TERMINAL CHAMBER

FIG. 19. BRASS PIPE 3' BACK FROM CREST

FIG. 20. HORIZONTAL SECTION THROUGH CORNER OF CREST

FIG. 21. VERTICAL SECTION THROUGH CREST

duct, the experiments were begun at the siphon chamber and were continued until 2.40 P. M.

In order to ascertain the time required for the water to pass from the weir at the siphon to the weirs at the terminal chamber, floats were put into the water below the siphon weir at regular intervals. They were received at the terminal chamber at intervals corresponding almost exactly. Accordingly, observations at the terminal weirs were regularly begun when the proper time had elapsed after the beginning of the siphon observations, and they were continued for the same length of time as at the siphon.

During the comparative observations care was taken not to disturb the gates at the head of the aqueduct, for it has been found that while it takes more than eight hours for the water to travel the length of the aqueduct, the slightest disturbance at the head gates sends an advance wave along the aqueduct with great rapidity. If one of these waves starts from the head of the aqueduct at the same time that a float is put into the aqueduct at the siphon chamber, the wave overtakes the float before it arrives at the terminal chamber. That is to say, the wave travels through 17 miles of aqueduct in less time than the water passes along the last 5 miles.

Table No. 5 shows the comparisons made between the weirs at siphon and terminal gate-chambers.

The mean ratio of the discharge (Q) at the siphon weir to the discharge (Q) at the terminal chamber was 0.9886, and all the discharges found at the terminal chamber were reduced to the standard of the siphon weir by the use of that ratio.

Leakage into the Aqueduct.—The leakage into the 5 miles of aqueduct was determined by weir measurements, and was found to amount to 0.558 cu. ft. per second.

Levels.—The zeros of the gauges were set by very careful spirit leveling, the probable error by least squares being 0.002 ft. in the distance of 1 800 ft.

Water Level Observations.—As a check on the spirit leveling the 48-in. pipes were alternately filled with water and shut off, so that the flow was stopped, and the elevations of the water surfaces were observed at both ends by reading the gauges. The readings at the two ends of the pipes were compared, and their differences were tabulated and plotted

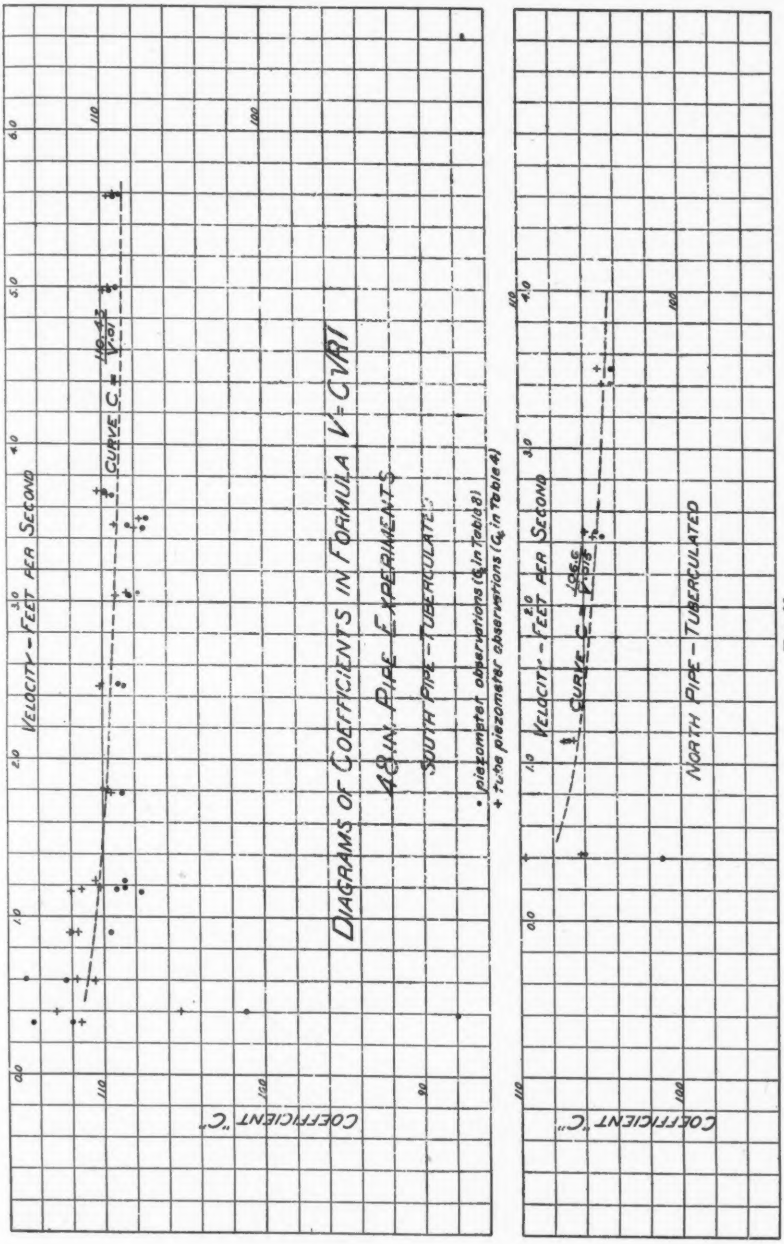

DIAGRAMS OF COEFFICIENTS IN FORMULA V=C√RI
48 IN. PIPE EXPERIMENTS
SOUTH PIPE - TUBERCULATED
• piezometer observations (C in Table 8)
+ tube piezometer observations (C in Table 4)
VELOCITY - FEET PER SECOND
CURVE C = 110.43/V.01
COEFFICIENT "C"
NORTH PIPE - TUBERCULATED
CURVE C = 106.6/V.015

Fig. 22.

All the differences in the case of the tube piezometers and fully 75% in the case of the other piezometers were in the same direction, whence it was concluded that the zeros of the gauges had not been set at exactly the same level. Tables Nos. 6 and 7 give a summary of the comparison. It appears from Table No. 6, embracing the outside piezometers, that in the case of the north pipe, the zero of the scale at the west end was probably too low by 0.0019 ft., and that in the case of the south pipe it was too low by 0.0020 ft., relatively to the zeros at the east end.

From Table No. 7, it appears that the zeros of the west tube gauge piezometers were likewise too low by 0.0083 ft. in the case of the north pipe, and by 0.0065 ft. in the case of the south pipe. These gauges had not been set with as great care as the outside piezometer gauges.

By the method of least squares it was found that the difference in elevation between water surfaces at piezometer gauges could be determined from the means of all the water-level observations with a probable error much smaller than the probable error in the spirit leveling. This is owing to the very large number of readings of the water level. A close analysis of them convinced the author that their mean could be relied upon within 0.001 ft.

In the tables the values c_1 and c_3 have been calculated upon the basis of the spirit leveling. In order to substitute the relation determined by the water-level observations, it is necessary to make a slight correction. The values as corrected are given in the tables, and marked c_2 and c_4. For ordinary velocities their difference from c_1 and c_3 is insignificant. The diagrams (Figs. 22 and 23) have been plotted, using the values of c_2 and c_4.

Oscillations in the Isolated Pipes.—The comparisons of the water-level observations just mentioned were noticeably different for different times. To account for these differences, it was suggested that the effect of the wind might cause a difference in the pressure of the atmosphere between the two ends of the pipe. If atmospheric differences existed, it was evident that a correction on that account should be applied to the observed losses of head in the flowing pipe.

It had been found that the two pairs of piezometers at the same section gave the same reading, and that, therefore, the use of either

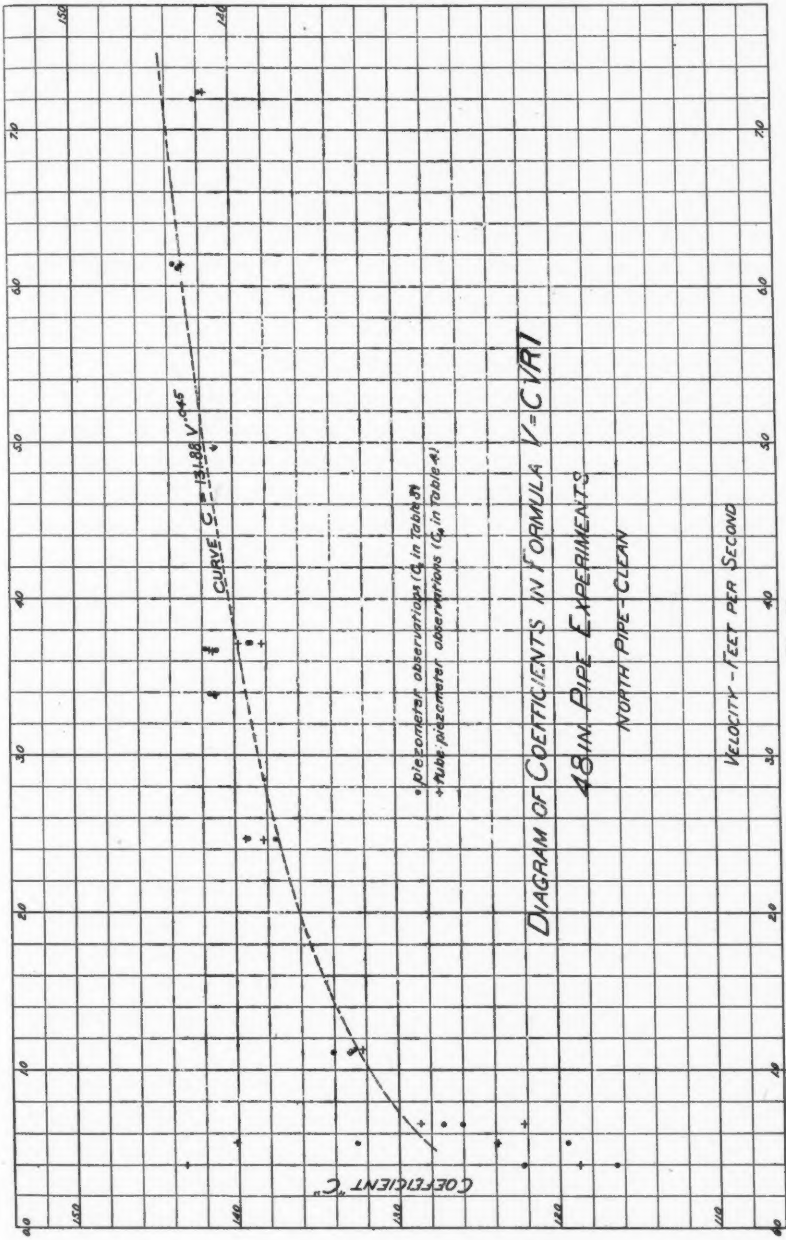


DIAGRAM OF COEFFICIENTS IN FORMULA V=C√RI
48 IN. PIPE EXPERIMENTS
NORTH PIPE-CLEAN
CURVE C = 131.88 V^.045
• piezometer observations
+ tube piezometer observations (C₄ in Table 4)
COEFFICIENT "C"
VELOCITY-FEET PER SECOND
150
140
130
120
110
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0

Fig. 23.

pair alone was sufficient. Accordingly, while the tube on one side of the gauge continued to be used for a pair of piezometers in the flowing pipe, the tube on the other side of the gauge was connected with the still pipe. Observations on the latter were continued during a large portion of the experimenting; and, as it was assumed that the same variations in atmospheric pressure were acting upon both pipes, it was intended that the results of each 100 minutes' observations of the flow should be corrected by an amount determined by the simultaneous observations on the still pipe. The comparative observations, however, did not afford a basis for making the corrections as contemplated.

There appeared to be no correspondence between the variations in the differences of water level and the variations in the velocity and direction of the wind. Moreover, for the same interval of time the difference of the readings on one set of gauges was often very different from that on the other set of gauges, and was opposite in direction in somewhat less than 25% of the observations of the outside piezometers.

The variations in question appeared to be due to an oscillating movement of the water in the pipe. The period of oscillation in the 48-in. pipe, if 1 800 ft. long, was found by calculation to be 33 seconds, neglecting the effects of friction. The observed period, being affected by friction, was from 60 to 70 seconds. The effect of the oscillations of the water in the pipe was shown on diagrams plotted from special readings made for the purpose on October 6th, 1894. It was seen from these plots that while an observer at one end of the pipe was reading the crest of the wave, the observer at the other end was reading the hollow, and that the period of oscillation was so nearly one minute that readings taken at intervals of two minutes did not give the mean position of the water surface; and it was at intervals of two minutes that the readings were taken during all of the observations in the tube piezometers, and on about half of the experiments on the other piezometers.

Correct results in such cases can only be obtained by taking the observations so often as to nullify the effect of the oscillations, which is often impracticable. The error was much smaller in the case of the readings taken every half minute, which almost eliminated the effect of the oscillations. The amplitude of the oscillations, as determined

in the piezometric readings, was, of course, modified by the throttling at the gauges. It was found that at the open end of the east end of the 48-in. pipe the amplitude was about 0.03 ft., while at the east piezometer it was 0.005 ft. If any correction were to be applied on account of the oscillation, it would, as above seen, be very small, and it would not be well worth making where there exists an uncertainty nearly as great arising from other causes.

It was found by experiment that readings of gauges similar to those used for the tube piezometers at the siphon are uncertain to the extent of 0.002 ft., probably due to variations in capillary attraction in the ½-in. glass tubes. The outside piezometer gauges had larger glass tubes. It further appeared from an actual test, continued throughout a whole day, that there is a liability to errors of observation in the case of the piezometric readings amounting to 0.001 ft., and to somewhat more than that in the case of the tube piezometers, which were unprovided with verniers. Four series of observations of 100 minutes each were made. There were four observers employed, two at each of the two piezometer gauges, and they changed ends several times during the day. One observer read the column on one side of the gauge, and the other, that on the other side. Readings were taken every half minute, the observers reading simultaneously for half the day, and alternately at quarter-minute intervals the other half day. The differences of one observer from the other on the mean of 100 minutes were 0.0003, 0.0006, 0.0003, 0.0003, 0.0006, 0.0001, 0.0013 and 0.0013.

The author has gone into this matter fully, not so much on account of its value in determining the coefficients, as for the purpose of showing the refinements to which these experiments were carried, and pointing out what perplexing sources of error are liable to be encountered in such work. In ordinary experiments to determine the losses of head it would be unnecessary to go to the expense of such fine apparatus.

Degree of Accuracy in Measurements and Results.—The approximate uniformity of the piezometric readings can be seen by a study of the tables, which give the highest and lowest readings in the different 20-minute intervals, with the range, which is generally less than 0.02 ft.

The length of the pipe has probably been obtained with a preci-

sion of 1 in 50 000, which is 0.002%, and would equal about 0.03 ft. in a length of 1 600 ft.

The accuracy of the leveling and of the reading of the gauges has already been discussed. Upon these elements the accuracy of the determination of the loss of head depends.

The measurement of the discharge is probably liable to an error of 1%, and, as the velocities vary directly as the discharge, the velocity is liable to an error of 1%, or, say, from an error of 0.003 ft. per second for the smallest velocity to 0.07 ft. per second for the largest. The coefficient c is in error about 1% if the velocity is in error 1 per cent.

Formula for Weirs.—Much study was given to the question what formula to use in computing the discharge of the weirs, and it was finally decided to use the result of Bazin's experiments, as best fitting the case in hand. The formula is $v = m\,L\,H\,\sqrt{2\,g\,h}$. The values of the coefficient m for each height of weir employed were tabulated from the results of Bazin's experiments and used in the computations.

Notation.—Quantities entering into the formulas are expressed as follows when English measures are used:

I = friction head in feet per foot of pipe.
v = mean velocity in feet per second.
R = hydraulic mean depth in feet.

Formula for Flow in Pipes.—For the want of any really satisfactory formula to express the law of flow in pipes generally, the familiar Chézy formula, $v = c\,\sqrt{R\,I}$, has been made the basis of study for these experiments. In the pipes in question, the diameter being 4 ft., $R = 1$ and vanishes, so that the formula becomes $v = c\sqrt{I}$. It being impossible to assign to c in that formula any one value which will fit all cases, the attempt has been made to find what different values of c will fit the various conditions experimented upon.

Simple Chézy Formula Sufficient Only for Particular Condition of Surface of Pipe.—In the tuberculated pipes experimented upon, a constant value of 110.43 for c, making the formula $v = 110.43\sqrt{I}$, fits the experiments fairly well for all the heads. The form $v = 100\sqrt{I}$ is still easier to remember, and is excellent to express the flow through 48-in.

pipe slightly more tuberculated, say with 20 years' service. For metric measures these formulas become $v = 60.97 \sqrt{R\,I}$ and $v = 55.21 \times \sqrt{R\,I}$, respectively. To fit the experiments on the clean pipe, however, different values of c are required for different heads.

The Substitution of Kutter's Coefficients Adapts the Formula to Different Cases and Particularly to Clean Pipe.—In substituting values for c the method of Kutter's formula is admirable in that it takes account separately of the different elements that modify the coefficient, to wit, the hydraulic mean depth, the loss of head and the condition of the surface as to roughness. The last is allowed for by the introduction of a quantity, represented by n, called the coefficient of roughness. This is of especial importance, it being found that the rusting of the interior of a pipe diminishes its capacity very much, as already stated in the case of the Rosemary siphon. In designing works a large allowance is necessarily made for this, if they are expected to last for many years. The coefficient c according to Kutter's formula fits well the experiments on the clean pipe, taking $n = 0.011$. The formula then becomes

$$v = \frac{206.2\,I + 0.00281}{1.458\,I + 0.000031} \times I^{\frac{1}{2}}.$$

To fit the experiments on the tuberculated pipe as nearly as possible with Kutter's formula, n should be taken about 0.014, which is about the same value that he uses for brickwork. The formula then becomes

$$v = \frac{171\,I + 0.00281}{1.582\,I + 0.0000393} \times I^{\frac{1}{2}}.$$

To fit what the author believes would be the condition of a pipe badly tuberculated, say by fifty years' service, n in Kutter's formula should be taken as large as 0.0157, and the formula would be

$$v = \frac{157\,I + 0.00281}{1.653\,I + 0.0000441} \times I^{\frac{1}{2}}.$$

This formula is not based on experiment.

In the case of the tuberculated pipes the Kutter formula does not fit the low heads, say for velocities of less than 1 ft. per second. At low velocities the loss of head due to friction is very small and difficult to measure with accuracy relatively to the magnitudes involved.

Hence the probable error is relatively large, and at the best the precise form of the curve which would graphically express c is doubtful for very low heads. As n is the coefficient of roughness, it was intended that the same value should be assigned to it in a pipe in any one given state, irrespectively of whether the velocity of the water running through it is great or small; an idea of the imperfection of the Kutter formula if applied to these experiments may therefore be obtained from the statement that instead of 0.014, as above mentioned for the value of n for considerable velocities, it would be necessary in the case of the Rosemary south pipe, in order to fit the Kutter formula for the velocity of 1.2 ft. per second, to make n about 0.013, and for the velocity of 0.7 ft. per second, about 0.012.

Formula Chosen for the Present Investigation.—It was found that for the author's experiments an exponential formula would fit the case of the tuberculated pipe much better, and of the clean pipe somewhat better than Kutter's formula.

The desired formula was obtained by the method of logarithmic homologues described by Professor Reynolds in the *Proceedings and Transactions* of the Royal Society, London, 1883. The logarithms of I were plotted as abscissas, and the logarithms of v as ordinates; and from drawing straight lines, coinciding as nearly as possible with the plotted points on these logarithmic diagrams, exponents were obtained from which the following formulas are derived:

		Feet.*	Meters.
For north pipe, cleaned..........(1)	$v = 165\ I^{\frac{1}{1.91}}$	$v = 171.3\ I^{\frac{1}{1.9}}$	$v = 94.57\ I^{\frac{1}{1.9}}\ R^{\frac{1}{2}}$
For north pipe, tuberculated.....(2)	$v = 99.493\ I^{\frac{1}{2.03}}$	$v = 110.43\ I^{\frac{1}{2}}$	$v = 60.97\ I^{\frac{1}{2}}\ R^{\frac{1}{2}}$
For south pipe, tuberculated.....(3)	$v = 105.41\ I^{\frac{1}{2.03}}$		

* R is omitted from the formula in English measures because it is unity.

The expressions in the last two columns are obtained by rounding off figures for greater simplicity; they might be used as the basis for computing tables if desired.

The curves plotted on the diagrams of c, Figs. 22 and 23, are based on calculation from formulas numbered (1) (2) and (3).

Experiments of Mr. Stearns.—The experiments recorded in this paper

possess an additional value from the fact that the coefficients for the same pipes when new were determined by F. P. Stearns, M. Am. Soc. C. E., as communicated to this Society in his paper read October 1st, 1884.*

By the three experiments which Mr. Stearns regarded as trustworthy the coefficient c in the Chézy formula, $v = c\sqrt{R\,I}$, had values as shown in the second column of the table below, for the velocities given in the first column respectively.

The corresponding coefficients as determined by the experiments of 1894–95 in the clean pipe (tubercles removed) calculated by the formula $c = 131.88\, v^{0.045}$ (the same value used in formula (1) above), are given in the third column.

Velocity.	c, 1880.	c, 1894–95.
3.738	140.14	139.94
4.965	142.11	141.74
6.195	144.09	143.16

Conclusion.—In referring to the number of years of service of pipes as indicative of the condition of the interior surface, it should be observed that in other localities the effect of use may not be the same as on the Boston Water-Works. Many waters, for example, containing lime produce a smooth white coating inside the pipes. It is greatly to be desired that more accurate observations and experiments should be made as to how the frictional loss of head is affected by such coating, and whether it becomes further modified by longer periods of service.

The results herewith presented led the author to the conclusion that piezometric gauges laid upon the bottom of a pipe and those screwed into the sides give equally accurate results and that these piezometers when properly arranged can be depended upon as certainly as can other hydraulic appliances of precision. The author is particular in calling attention to this fact on account of slurs that have been cast by some hydraulicians upon piezometric observations.

* See the *Transactions* of the American Society of Civil Engineers, Vol. xiv, p. 1.

In conclusion the author desires to express his obligations to Messrs. William E. Foss, Frank S. Hart and F. F. Moore, principal assistants in these experiments, to whose skill and zeal the success of the work is largely due, and to Fred. Brooks, M. Am. Soc. C. E., for advice in the preparation of this paper.

TABLE No. 1.—WEIR OBSERVATIONS (Terminal Chamber).

Using Bazin's values of m in formula $Q = m\ L\ H\ 2\sqrt{g\ H};\ g = 32.17$.

Experiments 216 or XLIV to LI were on north pipe clean; LI to LVI, inclusive, on south pipe tuberculated (see note to Table No. 2).

1	2	3		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
				EAST WEIR.								WEST WEIR.										
				Height of water on weir.								Height of water on weir.										
Date.	Number of experiment.	Time of beginning.	Time of ending.	No. observations.	Highest. Feet.	Lowest. Feet.	Range. Feet.	Mean. H. Feet.	Mean length of weir. L. Feet.	Coefficient from table. m.	Quantity in cubic feet, per second. Q.	No. observations.	Highest. Feet.	Lowest. Feet.	Range. Feet.	Mean. H. Feet.	Mean length of weir. L. Feet.	Coefficient from table. m.	Quantity in cubic feet per second. Q.	Total quantity. Column 11 plus column 19.	Total quantity, less 0.558 cubic feet per second, leakage.	Column 21, x 0.9886 to reduce to siphon weir.
1894.																						
Dec. 24th.	216	1.00	1.20	10	1.5081	1.5040	0.0041	1.5057	6.3244	0.4322	40.509	11	1.5265	1.5214	0.0051	1.5228	5.8403	0.4324	38.065	78.574	78.016	77.127
" 24th.	217	1.20	1.40	10	1.5070	1.5029	0.0041	1.5052	6.3244	0.4322	40.489	11	1.5262	1.5219	0.0043	1.5240	5.8403	0.4324	38.110	78.599	78.041	77.151
" 24th.	218	1.40	2.00	10	1.5072	1.5032	0.0040	1.5055	6.3244	0.4322	40.501	11	1.5272	1.5203	0.0069	1.5243	5.8403	0.4324	38.121	78.622	78.064	77.174
" 24th.	219	2.00	2.20	10	1.5090	1.5035	0.0055	1.5068	6.3244	0.4322	40.553	11	1.5275	1.5203	0.0072	1.5236	5.8403	0.4324	38.095	78.648	78.090	77.200
" 24th.	220	2.20	2.40	10	1.5083	1.5034	0.0049	1.5062	6.3244	0.4322	40.529	11	1.5250	1.5210	0.0040	1.5231	5.8403	9.4324	38.076	78.605	78.047	77.157
	(XLIV)	1.00	2.40	50	1.5090	1.5029	0.0061	1.5059	6.3244	0.4322	40.517	51	1.5275	1.5203	0.0072	1.5236	5.8403	0.4324	38.095	78.612	78.054	77.164
Dec. 24th.	(XLV)	4.20	6.00	50	1.5065	1.4989	0.0076	1.5032	6.3244	0.4322	40.408	51	1.5240	1.5171	0.0069	1.5207	5.8403	0.4324	37.986	78.394	77.836	76.949
1895.																						
Jan. 10th.	(XLVI)	2.40	4.20	51	1.0903	1.0854	0.0049	1.0876	6.3206	0.4285	24.641	50	1.1061	1.1001	0.0060	1.1029	5.8367	0.4286	23.242	47.883	47.325	46.785
" 10th.	(XLVII)	6.00	7.40	51	1.0940	1.0841	0.0099	1.0875	6.3206	0.4285	24.637	50	1.1091	1.0996	0.0095	1.1030	5.8367	0.4287	23.250	47.887	47.329	46.789
" 11th.	(XLVIII)	2.30	4.10	51	1.3168	1.3073	0.0095	1.3133	6.3200	0.4304	32.838	50	1.3337	1.3259	0.0078	1.3304	5.8364	0.4306	30.934	63.772	63.214	62.493
" 16th.	(XLIX)	2.00	3.40	51	1.6728	1.6660	0.0068	1.6692	6.3185	0.4338	47.414	50	1.6956	1.6866	0.0090	1.6914	5.8354	0.4340	44.686	92.100	91.542	90.498
" 16th.	(L)	5.20	7.00	51	1.6790	1.6718	0.0072	1.6761	6.3184	0.4339	47.719	50	1.7014	1.6931	0.0083	1.6972	5.8354	0.4341	44.926	92.645	92.087	91.037
" 23d.	(LI)	2.40	4.20	51	1.0770	1.0715	0.0055	1.0744	6.3207	0.4284	24.188	50	1.1026	1.0965	0.0061	1.0995	5.8367	0.4286	23.134	47.322	46.764	46.231
" 23d.	(LII)	6.00	7.40	51	1.0864	1.0740	0.0124	1.0792	6.3207	0.4285	24.356	50	1.1111	1.1003	0.0108	1.1041	5.8367	0.4287	23.285	47.641	47.083	46.546
" 24th.	(LIII)	2.30	4.10	51	1.3120	1.3030	0.0090	1.3077	6.3200	0.4303	32.621	50	1.3436	1.3351	0.0085	1.3391	5.8364	0.4306	31.238	63.859	63.301	62.579
" 24th.	(LIV)	5.50	7.30	51	1.3174	1.3065	0.0109	1.3117	6.3200	0.4304	32.778	50	1.3461	1.3379	0.0082	1.3428	5.8364	0.4307	31.375	64.153	63.595	62.870
" 25th.	(LV)	2.20	4.00	51	1.4120	1.4048	0.0072	1.4078	6.3197	0.4313	36.520	50	1.4444	1.4385	0.0059	1.4409	5.8362	0.4316	34.946	71.466	70.908	70.100
" 25th.	(LVI)	5.40	7.20	51	1.4152	1.4045	0.0107	1.4099	6.3197	0.4313	36.602	50	1.4472	1.4391	0.0081	1.4429	5.8362	0.4316	35.019	71.621	71.063	70.253

NOTE.—The temperatures during the experiments were as follows: 216, 36.7°; XLV, 36.8; XLVI, 37°; XLVII, 37°; XLVIII, 36.7°; XLIX, 35.5°; L, 35.3°; LI, 35.5°; LIII, 35.1°; LV, 34.9°.

TABLE No. 2. WEIR OBSERVATIONS (Siphon).*

Using Bazin's values of m in formula $Q = m\ L\ H \sqrt{2\,g\,H};\ g = 32.17$.

Experiments 1 or I to XXII were on the tuberculated south pipe, XXII to XXX on the north pipe tuberculated, and XXX to XLIV on the north pipe clean.

1	2	3		4	5	6	7	8	9	10	11	12
				HEIGHT OF WATER ON WEIR.								
Date.	Number of experiment.	Time of beginning.	Time of ending.	Number of observations.	Highest. Feet.	Lowest. Feet.	Range. Feet.	Mean. H. Feet.	Mean length of weir. Feet. L.	Coefficient from table. m.	Quantity in cubic feet per second. Q.	Temperature of water, Fahrenheit.
1894. September 4th. P.M..	1	1:20	1:40	10	1.8438	1.8277	0.0161	1.8347	4.9707	0.4421	43.805	64.2°
	2	1:40	2:00	11	1.8420	1.8302	0.0118	1.8368	4.9707	0.4422	43.890	
	3	2:00	2:20	11	1.8399	1.8332	0.0067	1.8368	4.9707	0.4422	43.890	
	4	2:20	2:40	11	1.8385	1.8356	0.0029	1.8372	4.9707	0.4422	43.905	
	5	2:40	3:00	11	1.8390	1.8358	0.0032	1.8375	4.9707	0.4422	43.916	
	(I)	1:20	3:00	50	1.8438	1.8277	0.0161	1.8366	4.9707	0.4422	43.883	
1894. September 5th. A.M..	(II)	10:00	11:40	51	1.4778	1.4700	0.0078	1.4740	4.9712	0.4373	31.205	66.2°
" 5th. P.M..	(III)	1:20	3:00	51	1.4710	1.4640	0.0070	1.4674	4.9712	0.4372	30.989	
" 6th. A.M..	(IV)	10:00	11:40	51	0.9143	0.8990	0.0153	0.9050	4.9724	0.4303	14.776	
" 6th. P.M..	(V)	1:20	3:00	51	0.9029	0.8951	0.0078	0.8990	4.9725	0.4303	14.629	
" 7th. A.M..	(VI)	10:00	11:40	51	0.4475	0.4380	0.0095	0.4431	4.9746	0.4311	5.074	65.1°
" 7th. P.M..	(VII)	1:20	3:00	51	0.4400	0.4333	0.0067	0.4368	4.9747	0.4312	4.967	65.1°
" 11th. A.M..	(VIII)	10:00	11:40	51	1.6973	1.6785	0.0188	1.6858	4.9709	0.4401	38.409	70.3°
" 11th. P.M..	(IX)	1:20	3:00	51	1.6832	1.6763	0.0069	1.6798	4.9709	0.4401	38.204	70.3°
" 12th A.M..	(X)	10:00	11:40	51	1.2058	1.1966	0.0092	1.2005	4.9717	0.4337	22.750	68.8°
" 12th. P.M..	(XI)	1:20	3:00	51	1.2036	1.1830	0.0206	1.1930	4.9717	0.4336	22.532	
" 13th. A.M..	(XII)	10:00	11:40	51	0.7775	0.7593	0.0182	0.7614	4.9732	0.4290	11.370	67.7°
" 13th. P.M..	(XIII)	1:20	3:00	51	0.7618	0.7525	0.0093	0.7590	4.9732	0.4290	11.316	
" 14th. A.M..	(XIV)	10:00	11:40	51	0.5900	0.5769	0.0131	0.5823	4.9740	0.4291	7.607	67.6°
" 14th. P.M..	(XV)	1:20	3:00	51	0.5796	0.5725	0.0071	0.5756	4 9740	0.4292	7.478	

October	4th. A.M..	(XVI)	10:00	11.40	51	1.8404	1.8170	0.0234	1.8302	4.9688	0.4421	43.628	61.4°
"	4th. P.M..	(XVII)	1:20	3.00	51	1.8595	1.8406	0.0189	1.8510	4.9687	0.4424	44.403	
"	5th. A.M..	(XVIII)	10:00	11:40	51	0.9405	0.9263	0.0142	0.9312	4.9702	0.4306	15.426	61.8°
"	5th. P.M..	(XIX)	1:20	3:00	51	0.9174	0.9102	0.0072	0.9136	4.9702	0.4304	14.984	
"	6th. A.M..	(XX)	10:00	11:40	51	0.3922	0.3860	0.0062	0.3883	4.9728	0.4323	4.172	61.6°
"	6th. P.M..	(XXI)	1:20	3:00	51	0.4067	0.3777	0.0290	0.3845	4.9728	0.4324	4.112	
"	18th. A.M..	(XXII)	10:00	11:40	51	1.8172	1.8007	0.0165	1.8101	4.9688	0.4418	42.882	53.3°
"	18th. P.M..	(XXIII)	1:20	3:00	48	1.8564	1.8324	0.0240	1.8430	4.9687	0.4423	44.105	
"	19th. A.M..	(XXIV)	10.00	11:40	51	1.4732	1.4635	0.0097	1.4690	4.9692	0.4373	31.034	52.8°
"	19th. P.M..	(XXV)	1:20	3:00	51	1.4613	1.4545	0.0068	1.4575	4.9693	0.4371	30.657	
"	20th. A.M..	(XXVI)	10:00	11:40	51	0.4568	0.4465	0.0103	0.4523	4.9724	0.4309	5.228	
"	20th. P.M..	(XXVII)	1:20	3:00	51	0.4445	0.4393	0.0052	0.4420	4.9724	0.4311	5.053	
"	30th. A.M..	(XXVIII)	10:00	11:40	50	0.8897	0.8801	0.0096	0.8847	4.9703	0.4301	14.269	
"	30th. P.M..	(XXIX)	1:20	3:00	50	0.8894	0.8828	0.0066	0.8860	4.9703	0.4301	14.300	
November	30th. A.M..	(XXX)	10:00	11:40	51	1.9035	1.8943	0.0092	1.8979	4.9693	0.4430	46.169	
"	30th. P.M..	(XXXI)	1:20	3:00	50	1.9053	1.8966	0.0087	1.9009	4.9693	0.4430	46.278	
December	1st. A.M..	(XXXII)	10:00	11:40	51	1.4751	1.4646	0.0105	1.4699	4.9700	1.4373	31.068	35.5°
"	1st. P.M..	(XXXIII)	1:20	3:00	51	1.4759	1.4641	0.0118	1.4714	4.9700	0.4373	31.115	
"	7th. A.M..	(XXXIV)	10:00	11:40	51	0.8809	0.8672	0.0137	0.8731	4.9714	0.4300	13.989	36.5°
"	7th. P.M..	(XXXV)	1:20	3:00	51	0.8845	0.8765	0.0080	0.8808	4.9713	0.4301	14.177	
"	8th. A.M..	(XXXVI)	10:00	11:40	51	0.4391	0.4315	0.0076	0.4369	4.9735	0.4312	4.968	37.3°
"	8th. P.M..	(XXXVII)	1:20	3:00	51	0.4410	0.4325	0.0085	0.4387	4.9735	0.4312	4.998	
"	13th. A.M..	(XXXVIII)	10:00	11:40	51	1.8108	1.7878	0.0230	1.8009	4.9694	0.4417	42.551	36.5°
"	13th. P.M..	(XXXIX)	1:20	3:00	51	1.8113	1.7877	0.0236	1.8013	4.9694	0.4417	42.565	
"	14th. A.M..	(XL)	10:00	11:40	51	0.6225	0.6113	0 0112	0.6168	4.9727	0.4289	8.287	37.0°
"	14th. P.M..	(XLI)	1:20	3:00	51	0.6249	0.6071	0.0178	0.6148	4.9727	0.4289	8.247	
"	15th. A.M..	(XLII)	10:00	11:40	51	0.5483	0.5323	0.0160	0.5362	4.9730	0.4295	6.727	38.3°
"	15th. P.M..	(XLIII)	1:20	3:00	49	0.5430	0.5350	0.0080	0.5388	4.9730	0.4295	6.776	

* It was intended originally to print the tables in full, but on account of the space required they have been condensed. Each experiment, covering 20 minutes and embracing ten observations, was numbered as a distinct experiment with arabic figures. Five of these experiments, covering 100 minutes, were united and a mean obtained, forming a set of means designated by Roman numerals. The latter only have been printed, but with each table a sample of the whole method on which the table was formed is given to show the slight variations in the 20-minute experiments.

TABLE No. 3.—Piezometer Observations.

1	2	3		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
				West Piezometer Readings.					East Piezometer Readings.										Results from columns 15 and 18 corrected for water levels.	
Date.	Number of experiment.	Time of beginning.	Time of ending.	Number of observations.	Highest. Feet.	Lowest. Feet.	Range. Feet.	Mean. Feet.	Number of observations.	Highest. Feet.	Lowest. Feet.	Range. Feet.	Mean. Feet.	Mean total fall in 1 615.7 feet of pipe. Feet.	Fall per foot of pipe I_1. Feet.	Discharge from table 1, column 11; and table 2, column 22. Cubic feet per second.	Mean velocity of flow in pipe. v. Feet per second.	Coefficient in $V = c_1\sqrt{RI_1}$. c_1.	I_2.	c_2.
South Pipe Tuberculated.—Length, 1 615.70 Ft.																				
1894. Sept. 4th, P.M..	1	1.20	1.40	21	6.548	6.541	0.007	6.5438	21	4.877	4.865	0.012	4.8695	1.6743	0.0010363	43.805	3.486	108.29		
	2	1.40	2.0	21	6.549	6.542	0.007	6.5439	21	4.873	4.860	0.013	4.8669	1.6770	0.0010379	43.890	3.493	108.41		
	3	2.0	2.20	21	6.552	6.544	0.008	6.5484	21	4.873	4.858	0.015	4.8650	1.6834	0.0010419	43.890	3.493	108.20		
	4	2.20	2.40	21	6.554	6.548	0.006	6.5513	21	4.876	4.867	0.009	4.8721	1.6792	0.0010393	43.905	3.494	108.38		
	5	2.40	3.0	21	6.557	6.552	0.005	6.5541	21	4.877	4.868	0.009	4.8728	1.6813	0.0010406	43.916	3.495	108.33		
	(I)	1.20	3.0	101	6.557	6.541	0.016	6.5483	101	4.877	4.858	0.019	4.8693	1.6790	0.0010392	43.883	3.492	108.33	0.0010383	108.38
1894. Sept. 5th, A.M..	(II)	10.0	11.40	101	5.347	5.338	0.009	5.3431	101	4.509	4.497	0.012	4.5023	0.8408	0.0005204	31.205	2.483	108.86	0.0005195	108.96
" 5th, P.M..	(III)	1.20	3.0	101	5.337	5.330	0.007	5.3340	101	4.507	4.497	0.010	4.5006	0.8334	0.0005158	30.989	2.466	108.58	0.0005149	108.68
" 6th, A.M..	(IV)	10.0	11.40	101	5.345	5.340	0.005	5.3418	101	5.159	5.146	0.013	5 1530	0.1888	0.0001169	14.776	1.176	108.77	0.0001160	109.20
" 6th, P.M..	(V)	1.20	3.0	101	5.345	5.341	0.004	5.3432	101	5.159	5.149	0.010	5.1528	0.1904	0.0001178	14.629	1.164	107.24	0.0001169	107.66
" 7th, A.M..	(VI)	10.0	11.40	101	6.056	6.048	0.008	6.0513	101	6.026	6.023	0.003	6.0241	0.0272	0.0000168	5.074	0.404	98.40	0.0000159	101.23
" 7th, P.M..	(VII)	1.20	3.0	51	6.065	6.061	0.004	6.0617	51	6.031	6.026	0.005	6.0276	0.0341	0.0000211	4.967	0.395	86.04	0.0000202	88.00
" 11th, A.M..	(VIII)	10.0	11.40	51	6.026	6.003	0.023	6.0141	51	4.723	4.704	0.019	4.7133	1.3008	0.0008051	38.409	3.057	107.72	0.0008042	107.78
" 11th, P.M..	(IX)	1.20	3.0	51	5.998	5.975	0.023	5.9849	51	4.717	4.702	0.015	4.7108	1.2741	0.0007886	38.204	3.040	108.26	0.0007877	108.32
" 12th, A.M..	(X)	10.0	11.40	51	5.872	5.861	0.011	5.8681	51	5.438	5.419	0.019	5.4287	0.4394	0.0002720	22.750	1.810	109.78	0.0002711	109.97
" 12th, P.M..	(XI)	1.20	3.0	51	5.868	5.862	0.006	5.8641	51	5.433	5.414	0.019	5.4238	0.4404	0.0002726	22.532	1.793	108.60	0.0002717	108.79
" 13th, A.M..	(XII)	10.0	11.40	51	6.395	6.388	0.007	6.3921	51	6.287	6.284	0.003	6.2852	0.1069	0.0000662	11.370	0.905	111.23	0.0000653	112.02
" 13th, P.M..	(XIII)	1.20	3.0	51	6.398	6.391	0.007	6.3950	51	6.287	6.282	0.005	6.2844	0.1106	0.0000685	11.316	0.901	108.84	0.0000676	109.59
" 14th, A.M..	(XIV)	10.0	11.40	51	6.152	6.144	0.008	6.1484	51	6.106	6.100	0.006	6.1020	0.0464	0.0000287	7.607	0.605	112.96	0.0000278	114.83
" 14th, P.M..	(XV)	1.20	3.0	51	6.148	6.142	0.006	6.1453	51	6.101	6.097	0.004	6.0985	0.0468	0.0000290	7.478	0.595	110.57	0.0000281	112.39
Oct. 4th, A.M..	(XVI)	10.0	11.40	51	6.574	6.515	0.059	6.5465	51	4.868	4.848	0.020	4.8580	1.6885	0.0010451	43.628	3.472	107.39	0.0010442	107.44
" 4th, P.M..	(XVII)	1.20	3.0	51	6.655	6.617	0.038	6.6374	51	4 892	4.869	0.023	4 8815	1.7559	0.0010868	44.403	3.533	107.18	0.0010859	107.23

Oct. 5th, A.M..	(XVIII)	10.0	11.40	51	5.407	5.392	0.015	5.4008	50	5.204	5.184	0.020	5.1932	0.2076	0.0001285	15.426	1.228	108.30	0.0001276	108.69
" 5th, P.M..	(XIX)	1.20	3.0	51	5.382	5.372	0.010	5.3762	51	5.191	5.174	0.017	5.1803	0.1959	0.0001212	14.984	1.192	108.29	0.0001203	108.71
" 6th, A.M..	(XX)	10.0	11.40	51	6.026	6.017	0.009	6.0205	51	6.012	6.000	0.012	6.0054	0.0151	0.0000093	4.172	0.332	108.61	0.0000084	114.44
" 6th, P.M..	(XXI)	1.20	3.0	51	6.023	6.009	0.014	6.0129	51	6.005	5.983	0.022	5.9976	0.0153	0.0000095	4.112	0.327	106.34	0.0000086	111.97

North Pipe Tuberculated.—Length, 1 615.70 Ft.

" 18th, A.M..	(XXII)	10.0	11.40	51	6.645	6.626	0.019	6.6339	51	4.915	4.883	0.032	4.8996	1.7343	0.0010734	42.882	3.412	104.15	0.0010717	104.23
" 18th, P.M..	(XXIII)	1.20	3.0	51	6.802	6.739	0.063	6.7700	51	4.953	4.919	0.034	4.9345	1.8355	0.0011300	44.105	3.510	104.13	0.0011343	104.21
" 19th, A.M..	(XXIV)	10.0	11.40	396	5.442	5.415	0.027	5.4254	211	4.554	4.516	0.038	4.5316	0.8938	0.0005532	31.034	2.470	105.00	0.0005515	105.16
" 19th, P.M..	(XXV)	1.20	3.0	397	5.409	5.399	0.010	5.4033	199	4.532	4.519	0.013	4.5249	0.8784	0.0005437	30.657	2.440	104.63	0.0005420	104.79
" 20th, A.M..	(XXVI)	10.0	11.40	201	5.956	5.953	0.003	5.9541	201	5.929	5.924	0.005	5.9265	0.0276	0.0000171	5.228	0.416	100.66	0.0000154	105.98
" 20th, P.M..	(XXVII)	1.20	3.0	201	5.954	5.940	0.014	5.9507	201	5.925	5.921	0.004	5.9225	0.0282	0.0000175	5.053	0.402	96.24	0.0000158	101.21
" 30th, A.M..	(XXVIII)	10.0	11.40	201	5.329	5.322	0.007	5.3258	201	5.150	5.129	0.021	5.1416	0.1842	0.0001140	14.269	1.135	106.34	0.0001123	107.13
" 30th, P.M..	(XXIX)	1.20	3.0	201	5.332	5.328	0.004	5.3299	201	5.151	5.139	0.012	5.1443	0.1856	0.0001149	14.300	1.138	106.18	0.0001132	106.96

North Pipe Clean.—Length, 1 615.70 Ft.

Nov. 30th, A.M..	(XXX)	10.0	11.40	51	6.112	6.081	0.031	6.0971	51	5.012	4.987	0.025	4.9991	1.0980	0.0006796	46.169	3.674	140.93	0.0006779	141.10
" 30th, P.M..	(XXXI)	1.20	3.0	197	6.106	6.088	0.018	6.0966	201	5.016	4.991	0.025	5.0035	1.0931	0.0006765	46.278	3.683	141.59	0.0006748	141.77
Dec. 1st, A.M..	(XXXII)	10.0	11.40	201	5.072	5.047	0.025	5.0588	199	4.543	4.524	0.019	4.5335	0.5253	0.0003251	31.068	2.472	137.11	0.0003234	137.46
" 1st, P.M..	(XXXIII)	1.20	3.0	201	5.056	5.042	0.014	5.0487	196	4.545	4.523	0.022	4.5348	0.5139	0.0003181	31.115	2.476	138.84	0.0003164	139.21
" 7th, A.M..	(XXXIV)	10.0	11.40	201	6.523	6.510	0.013	6.5177	198	6.411	6.393	0.018	6.4026	0.1141	0.0000706	13.989	1.113	132.47	0.0000689	134.07
" 7th, P.M..	(XXXV)	1.20	3.0	201	6.535	6.522	0.013	6.5288	198	6.416	6.403	0.013	6.4094	0.1194	0.0000739	14.177	1.128	131.24	0.0000722	132.75
" 8th, A.M..	(XXXVI)	10.0	11.40	201	6.014	6.009	0.005	6.0118	201	5.993	5.989	0.004	5.9905	0.0213	0.0000132	4.968	0.395	108.88	0.0000115	116.51
" 8th, P.M..	(XXXVII)	1.20	3.0	197	6.017	6.011	0.006	6.0135	201	5.996	5.990	0.006	5.9937	0.0198	0.0000123	4.998	0.398	113.62	0.0000106	122.26
" 13th, A.M..	(XXXVIII)	10.0	11.40	201	5.835	5.809	0.026	5.8200	201	4.907	4.874	0.033	4.8885	0.9315	0.0005765	42.551	3.386	141.02	0.0005748	141.22
" 13th, P.M..	(XXXIX)	1.20	3.0	201	5.833	5.799	0.034	5.8141	201	4.909	4.871	0.038	4.8889	0.9252	0.0005726	42.565	3.387	141.55	0.0005709	141.76
" 14th, A.M..	(XL)	10.0	11.40	201	6.182	6.169	0.013	6.1734	199	6.137	6.123	0.014	6.1273	0.0461	0.0000285	8.287	0.659	123.46	0.0000268	127.24
" 14th, P.M..	(XLI)	1.20	3.0	194	6.175	6.166	0.009	6.1711	201	6.131	6.121	0.010	6.1246	0.0465	0.0000288	8.247	0.656	122.33	0.0000271	126.04
" 15th, A.M..	(XLII)	10.0	11.40	201	6.097	6.085	0.012	6.0900	200	6.060	6.052	0.008	6.0549	0.0351	0.0000217	6.727	0.535	114.85	0.0000200	119.54
" 15th, P.M..	(XLIII)	1.20	3.0	196	6.096	6.085	0.011	6.0913	201	6.064	6.060	0.004	6.0619	0.0294	0.0000182	6.776	0.539	126.40	0.0000165	132.64
" 24th, A.M..	(XLIV)	10.0	11.40	188	6.002	5.932	0.070	5.9673	192	3.090	2.944	0.146	3.0106	2.9567	0.0018300	77.164	6.141	143.54	0.0018283	143.61
" 24th, P.M..	(XLV)	1.20	3.0	201	5.997	5.922	0.075	5.9604	196	3.089	2.912	0.177	3.0052	2.9552	0.0018291	76.949	6.123	143.18	0.0018274	143.25
1895.																				
Jan. 10th, A.M..	(XLVI)	10.0	11.40	187	5.953	5.930	0.023	5.9393	185	4.831	4.730	0.101	4.7786	1.1607	0.0007184	46.785	3.723	138.91	0.0007167	139.07
" 10th, P.M..	(XLVII)	1.20	3.0	186	5.960	5.930	0.030	5.9466	235	4.845	4.726	0.119	4.7834	1.1632	0.0007199	46.789	3.723	138.77	0.0007182	138.93
" 11th, A.M..	(XLVIII)	10.0	11.40	170	7.207	7.159	0.048	7.1835	186	5.217	5.139	0.078	5.1751	2.0084	0.0012431	62.493	4.973	141.05	0.0012414	141.14
" 16th, A.M..	(XLIX)	10.0	11.40	182	7.631	7.556	0.075	7.6012	191	3.477	3.439	0.038	3.4547	4.1465	0.0025664	90.498	7.202	142.16	0.0025647	142.21
" 16th, P.M..	(L)	1.20	3.0	182	7.746	7.680	0.066	7.7088	188	3.516	3.464	0.052	3.4902	4.2186	0.0026110	91.037	7.245	141.78	0.0026093	141.83

South Pipe Tuberculated.—Length, 1 615.70 Ft.

" 23d, A.M..	(LI)	10.0	11.40	186	6.015	5.990	0.025	6.0013	186	4.226	4.148	0.078	4.1742	1.8271	0.0011308	46.231	3.679	109.40	0.0011299	109.44
" 23d, P.M..	(LII)	1.20	3.0	180	6.037	6.010	0.027	6.0252	186	4.234	4.157	0.077	4.1847	1.8405	0.0011391	46.546	3.704	109.75	0.0011382	109.79
" 24th, A.M..	(LIII)	10.0	11.40	186	6.652	6.613	0.039	6.6323	178	3.368	3.225	0.143	3.2902	3.3421	0.0020685	62.579	4.980	109.49	0.0020676	109.51
" 24th, P.M..	(LIV)	1.20	3.0	185	6.717	6.689	0.028	6.7021	187	3.399	3.252	0.147	3.3017	3.4004	0.0021046	62.870	5.003	109.06	0.0021037	109.08
" 25th, A.M..	(LV)	10.0	11.40	170	6.873	6.844	0.029	6.8574	187	2.686	2.625	0.061	2.6378	4.2196	0.0026116	70.100	5.578	109.16	0.0026107	109.18
" 25th, P.M..	(LVI)	1.20	3.0	157	6.921	6.895	0.026	6.9098	187	2.662	2.634	0.028	2.6495	4.2603	0.0026368	70.253	5.591	108.87	0.0026359	108.89

TABLE No. 4.—Tube Piezometer Observations.

1	2	3		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
				West Tube Piezometer Readings.					East Tube Piezometer Readings.									Results from cols. 15 and 17 corrected for water levels.	
Date.	Number of experiment.	Time of beginning.	Time of ending.	Number of observations.	Highest. Feet.	Lowest. Feet.	Range. Feet.	Mean. Feet.	Number of observations.	Highest. Feet.	Lowest. Feet.	Range. Feet.	Mean. Feet.	Mean total fall in pipe. Feet.	Fall per foot of pipe. I_3. Feet.	Mean velocity of flow in pipe. From table 3, col. 17, v. Feet per second.	Coefficient in $v = c_3 \sqrt{R I_3}$. c_3.	I_4.	c_4.
South Pipe Tuberculated.—Length, 1 747.96 Ft.																			
1894. Sept. 4th, P.M..	1	1.20	1 40	11	6.639	6 631	0.008	6.6345	11	4.855	4.849	0.006	4.8508	1 7837	0.0010204	3.486	109.12		
	2	1.40	2.0	11	6.640	6.632	0.008	6.6357	11	4.850	4.845	0.005	4.8475	1.7882	0.0010230	3.493	109.20		
	3	2.0	2.20	11	6.643	6.635	0.008	6.6384	11	4.851	4.845	0.006	4.8493	1.7891	0.0010235	3.493	109.17		
	4	2.20	2.40	11	6.643	6 637	0.006	6.6420	11	4.850	4.848	0 002	4.8480	1.7940	0.0010263	3.494	109.06		
	5	2.40	3.0	11	6.645	6.638	0.007	6.6428	11	4.848	4.846	0.002	4.8470	1.7958	0.0010274	3.495	109.03		
	(I)	1.20	3.0	51	6.645	6.631	0.014	6.6387	51	4.855	4.845	0.010	4.8485	1.7902	0.0010242	3.492	109.12	0.0010205	109.32
1894. Sept. 5th, A.M..	(II)	10.0	11.40	51	5.398	5.383	0.015	5 3898	51	4.505	4.483	0.022	4.4931	0.8967	0.0005130	2.483	109.64	0.0005093	110.04
" 5th, P.M..	(III)	1.20	3.0	51	5.375	5.368	0.007	5.3710	51	4.491	4.486	0.005	4.4885	0.8825	0.0005049	2.466	109.75	0.0005012	110.16
" 6th, A.M.	(IV)	10.0	11.40	51	5.351	5.345	0.006	5.3477	51	5.155	5.140	0.015	5.1464	0.2013	0.0001152	1.176	109.57	0.0001115	111.38
" 6th, P.M..	(V)	1.20	3.0	51	5.341	5.338	0.003	5.3394	51	5.150	5.140	0.010	5.1443	0.1951	0.0001116	1.164	110.19	0.0001079	112.07
" 7th, A.M..	(VI)	10.0	11.40	51	6.053	6.049	0 004	6.0514	51	6.023	6.016	0.007	6.0192	0.0322	0.0000184	0.404	94.07	0.0000147	105.30
" 7th, P.M..	(VII)	1.20	3.0	51	6.043	6.041	0.002	6.0418	51	6.016	6.013	0.003	6.0139	0.0279	0.0000160	0.395	98.94	0.0000123	112.97
" 11th, A.M..	(VIII)	10.0	11.40	85	6.109	6.085	0.026	6.0964	51	4.715	4.696	0.019	4.7035	1.3929	0.0007969	3.057	108.28	0.0007932	108.53
" 11th, P.M..	(IX)	1.20	3.0	51	6 072	6.053	0.019	6.0618	51	4.704	4.698	0.006	4.6995	1.3623	0.0007794	3.040	108.90	0.0007757	109 16
" 12th, A.M..	(X)	10.0	11.40	49	5.903	5.900	0.003	5.9017	51	5.425	5.408	0.017	5.4193	0.4824	0.0002760	1.810	108.98	0.0002723	109.72
" 12th, P.M..	(XI)	1.20	3.0	51	5.892	5.884	0.008	5.8880	51	5.425	5.405	0.020	5.4129	0.4751	0.0002718	1.793	108.76	0.0002681	109.51
" 13th, A.M..	(XII)	10.0	11.40	51	6.402	6.399	0.003	6.4016	51	6.285	6 277	0.008	6.2803	0.1213	0.0000694	0.905	108.61	0.0000657	111.64
" 13th, P.M..	(XIII)	1.20	3.0	51	6.398	6.395	0.003	6.3968	51	6 281	6.275	0.006	6.2776	0.1192	0.0000682	0.901	109.05	0.0000645	112.15
" 14th, A.M..	(XIV)	10.0	11.40	51	6.163	6.156	0.007	6.1591	51	6.106	6.098	0.008	6.1013	0.0578	0.0000331	0.605	105 27	0.0000294	111.74
" 14th, P.M..	(XV)	1.20	3.0	51	6.153	6 150	0.003	6.1523	51	6.097	6.094	0.003	6.0952	0.0571	0.0000327	0.595	104.12	0.0000290	110.61
Oct. 4th, A.M..	(XVI)	10.0	11.40	51	6.688	6.625	0.063	6.6579	51	4 852	4.828	0.024	4.8434	1.8145	0.0010381	3.472	107.76	0.0010344	107.95
" 4th, P.M..	(XVII)	1.20	3.0	51	6.770	6.728	0.042	6.7527	51	4.874	4.857	0.017	4.8654	1.8873	0.0010797	3.533	107.53	0.0010760	107.72
5th, A.M..	(XVIII)	10.0	11.40	51	5.422	5.395	0.027	5.4073	51	5.196	5.177	0.019	5.1851	0.2222	0.0001271	1.228	108.88	0.0001234	110.51

Oct. 5th, P.M..	(XIX)	1.20	3.0	51	5.383	5.375	0.008	5.3793	51	5.177	5.162	0.015	5.1684	0.2109	0.0001207	1.192	108.55	0.0001170	110.26
" 6th, A.M..	(XX)	10.0	11.40	51	6.024	6.020	0.004	6.0221	51	6.002	5.997	0.005	6.0001	0.0220	0.0000126	0.332	93.59	0.0000089	111.50
" 6th, P.M..	(XXI)	1.20	3.0	51	6.018	6.011	0.007	6.0141	51	6.012	5.992	0.020	5.9972	0.0169	0.0000097	0.327	105.24	0.0000060	134.15
North Pipe Tuberculated.—Length, 1 748.10 Ft.																			
" 18th, A.M..	(XXII)	10.0	11.40	51	6.755	6.731	0.024	6.7418	51	4.895	4.854	0.041	4.8804	1.8614	0.0010648	3.412	104.57	0.0010600	104.80
" 18th, P.M..	(XXIII)	1.20	3.0	50	6.913	6.843	0.070	6.8776	51	4.945	4.899	0.046	4.9179	1.9597	0.0011210	3.510	104.83	0.0011162	105.05
" 19th, A.M..	(XXIV)	10.0	11.40	51	5.493	5.469	0.024	5.4795	51	4.530	4.505	0.025	4.5200	0.9595	0.0005489	2.470	105.41	0.0005441	105.87
" 19th, P.M..	(XXV)	1.20	3.0	51	5.461	5.443	0.018	5.4510	51	4.515	4.499	0.016	4.5059	0.9451	0.0005406	2.440	104.92	0.0005358	105.38
" 20th, A.M..	(XXVI)	10.0	11.40	51	5.959	5.949	0.010	5.9538	51	5.923	5.913	0.010	5.9177	0.0351	0.0000201	0.416	92.84	0.0000153	106.25
" 20th, P.M..	(XXVII)	1.20	3.0	51	5.943	5.939	0.004	5.9410	51	5.910	5.909	0.001	5.9092	0.0318	0.0000182	0.402	94.27	0.0000134	109.66
" 30th, A.M..	(XXVIII)	10.0	11.40	51	5.348	5.343	0.005	5.3447	50	5.149	5.133	0.016	5.1405	0.2042	0.0001168	1.135	105.06	0.0001120	107.26
" 30th, P.M..	(XXIX)	1.20	3.0	51	5.353	5.351	0.002	5.3519	51	5.152	5.135	0.017	5.1446	0.2073	0.0001186	1.138	104.50	0.0001138	106.66
North Pipe Clean.—Length, 1 748.10 Ft.																			
Nov. 30th, A.M..	(XXX)	10.0	11.40	46	6.189	6.175	0.014	6.1797	51	5.001	4.981	0.020	4.9906	1.1891	0.0006802	3.674	140.87	0.0006754	141.36
" 30th, P.M..	(XXXI)	1.20	3.0	46	6.186	6.183	0.003	6.1842	51	5.002	4.983	0.019	4.9920	1.1922	0.0006820	3.683	141.02	0.0006772	141.51
Dec. 1st, A.M..	(XXXII)	10.0	11.40	46	5.095	5.089	0.006	5.0915	36	4.531	4.514	0.017	4.5239	0.5676	0.0003247	2.472	137.20	0.0003199	138.21
" 1st, P.M..	(XXXIII)	1.20	3.0	47	5.090	5.083	0.007	5.0858	51	4.533	4.520	0.013	4.5257	0.5601	0.0003204	2.476	138.33	0.0003156	139.37
" 7th, A.M..	(XXXIV)	10.0	11.40	46	6.538	6.525	0.013	6.5312	51	6.408	6.391	0.017	6.4004	0.1308	0.0000748	1.113	128.69	0.0000700	132.98
" 7th, P.M.	(XXXV)	1.20	3.0	46	6.549	6.536	0.013	6.5442	51	6.414	6.401	0.013	6.4086	0.1356	0.0000776	1.128	128.10	0.0000728	132.21
" 8th, A.M..	(XXXVI)	10.0	11.40	46	6.018	6.010	0.008	6.0133	51	5.995	5.989	0.006	5.9917	0.0216	0.0000124	0.395	112.46	0.0000076	143.32
" 8th, P.M..	(XXXVII)	1.20	3.0	49	6.024	6.018	0.006	6.0220	51	5.997	5.992	0.005	5.9941	0.0279	0.0000160	0.398	99.56	0.0000112	118.78
" 13th, A.M..	(XXXVIII)	10.0	11.40	85	5.905	5.878	0.027	5.8929	51	4.894	4.865	0.029	4.8783	1.0146	0.0005804	3.386	140.55	0.0005756	141.13
" 13th, P.M..	(XXXIX)	1.20	3.0	97	5.908	5.873	0.035	5.8912	51	4.887	4.862	0.025	4.8764	1.0148	0.0005805	3.387	140.58	0.0005757	141.16
" 14th, A.M..	(XL)	10.0	11.40	48	6.188	6.178	0.010	6.1823	51	6.132	6.124	0.008	6.1281	0.0542	0.0000310	0.659	118.43	0.0000262	128.69
" 14th, P.M..	(XLI)	1.20	3.0	48	6.186	6.179	0.007	6.1819	50	6.129	6.117	0.012	6.1232	0.0587	0.0000336	0.656	113.25	0.0000288	122.22
" 15th, A.M..	(XLII)	10.0	11.40	47	6.097	6.089	0.008	6.0925	51	6.064	6.052	0.012	6.0587	0.0338	0.0000193	0.535	121.74	0.0000145	140.16
" 15th, P.M..	(XLIII)	1.20	3.0	47	6.102	6.096	0.006	6.0982	51	6.061	6.054	0.007	6.0568	0.0414	0.0000237	0.539	110.80	0.0000189	123.92
" 24th, A.M..	(XLIV)	10.0	11.40	93	6.211	6.175	0.036	6.1943	46	2.992	2.952	0.040	2.9638	3.2305	0.0018480	6.141	142.84	0.0018432	143.02
" 24th, P.M..	(XLV)	1.20	3.0	49	6.183	6.163	0.020	6.1733	46	3.000	2.953	0.047	2.9692	3.2041	0.0018329	6.123	143.03	0.0018281	143.22
1895.																			
Jan. 10th, A.M..	(XLVI)	10.0	11.40	46	6.030	6.021	0.009	6.0264	46	4.832	4.720	0.112	4.7773	1.2491	0.0007145	3.723	139.28	0.0007097	139.75
" 10th, P.M..	(XLVII)	1.20	3.0	46	6.051	6.033	0.018	6.0426	46	4.812	4.707	0.105	4.7654	1.2772	0.0007306	3.723	137.75	0.0007258	138.20
" 11th, A.M..	(XLVIII)	10.0	11.40	46	7.345	7.311	0.034	7.3282	46	5.193	5.112	0.081	5.1513	2.1769	0.0012453	4.973	140.92	0.0012405	141.19
" 16th, A.M..	(XLIX)	10.0	11.40	46	7.963	7.863	0.100	7.9107	46	3.419	3.387	0.032	3.4056	4.5051	0.0025771	7.202	141.86	0.0025723	141.99
" 16th, P.M..	(L)	1.20	3.0	46	8.061	7.984	0.077	8.0204	47	3.512	3.358	0.154	3.4360	4.5844	0.0026225	7.245	141.47	0.0026177	141.60
South Pipe Tuberculated.—Length, 1 747.96 Ft.																			
Jan. 23d, A.M..	(LI)	10.0	11.40	51	6.135	6.113	0.022	6.1249	51	4.180	4.122	0.058	4.1536	1.9713	0.0011278	3.679	109.55	0.0011241	109.73
" 23d, P.M..	(LII)	1.20	3.0	51	6.163	6.144	0.019	6.1524	51	4.232	4.132	0.100	4.1735	1.9789	0.0011321	3.704	110.09	0.0011284	110.27
" 24th, A.M..	(LIII)	10.0	11.40	51	6.869	6.835	0.034	6.8538	51	3.271	3.232	0.039	3.2542	3.5996	0.0020593	4.980	109.74	0.0020556	109.84
" 24th, P.M..	(LIV)	1.20	3.0	51	6.935	6.916	0.019	6.9275	51	3.360	3.202	0.158	3.2765	3.6510	0.0020887	5.003	109.47	0.0020850	109.57
" 25th, A.M..	(LV)	10.0	11.40	51	7.150	7.128	0.022	7.1362	51	2.721	2.565	0.156	2.6047	4.5315	0.0025925	5.578	109.56	0.0025888	109.64
" 25th, P.M..	(LVI)	1.20	3.0	51	7.204	7.188	0.016	7.1961	51	2.623	2.601	0.022	2.6106	4.5855	0.0026233	5.591	109.15	0.0026196	109.23

TABLE No. 5.—Comparison Between Siphon and Terminal Chamber Weirs.

Using Basin's values of m in the formula $Q = m\ L\ H\ \sqrt{2\ g\ H}$; $g = 32.17$.

Observations at Siphon Weir.

1	2	3	4		5	6	7	8	9	10
Date.	Number of experiment.	Temperature of water, Fahrenheit.	Time of beginning.	Time of ending.	Number of observations.	Mean height of water on weir. H. Feet.	Mean length of weir. L. Feet.	Coefficient from table. m.	Quantity in cubic feet per second. Q.	Ratio of quantity at siphon weir to quantity at terminal weirs.
1894.										
November 13th	1	38.8°	9.00 A.M.	12.20 P.M.	41	1.8897	4.9693	0.4429	45.860	0.9915
" 15th	2	38.7°	9.00 A.M.	1.40 P.M.	57	1.8748	4.9693	0.4427	45.298	0.9926
" 16th	3	39.0°	9.00 A.M.	1.40 P.M.	57	1.8790	4.9693	0.4427	45.450	0.9948
" 30th	4	35.5°	10.00 A.M.	11.40 A.M.	51	1.8979	4.9693	0.4430	46.169	0.9919
December 1st	5	35.5°	10.00 A.M.	11.40 A.M.	51	1.4699	4.9700	0.4373	31.068	0.9884
" 13th	6	....	10.00 A.M.	11.20 A.M.	41	1.8021	4.9694	0.4417	42.593	0.9924
" 21st	7	....	9.00 A.M.	12.20 P.M.	81	1.9392	4.9692	0.4435	47.737	0.9783
	Mean	....	....	....	....	....	....	....	....	0.9886

Observations at Terminal Weirs.

1	2	3	4		5	6	7	8	9	10	11	12	13	14	15	16
					East Weir.					West Weir.						
Date.	Number of experiment.	Temperature of water. Fahrenheit.	Time of beginning.	Time of ending.	Number of observations.	Mean height of water on weir. *H.* Feet.	Mean length of weir. *L.* Feet.	Coefficient from table. *m.*	Quantity in cubic feet per second. *Q.*	Number of observations.	Mean height of water on weir. *H.* Feet.	Mean length of weir. *L.* Feet.	Coefficient from table. *m.*	Quantity in cubic feet per second. *Q.*	Total quantity in cubic feet per second.	Total quantity less 0.558 cu. ft. per second leakage. Cubic feet per second.
1894.			P.M.	P.M.												
November 13th......	1	....	1.40	4.58	50	1.0720	6.3259	0.4284	24.127	50	1.0848	5.8411	0.4285	22.684	46.811	46.253
" 15th......	2	39.1°	2.20	7.00	141	1.6403	6.3238	0.4335	46.195	....	......	......	......	......	46.195	45.637
" 16th......	3	39.1°	2.20	7.00	....	......	......	......	......	140	1.7399	5.8396	0.4345	46.709	46.709	46.151
" 30th......	4	36.1°	3.20	5.00	51	1.6613	6.3237	0.4337	47.106	....	......	......	......	......	47.106	46.548
December 1st......	5	36.1°	4.30	6.10	....	......	......	......	......	51	1.3594	5.8408	0.4308	31.990	31.990	31.432
" 13th......	6	36.6°	3.00	4.20	40	1.0206	6.3261	0.4280	22.393	41	1.0339	5.8411	0.4281	21.086	43.479	42.921
" 21st......	7	37.1°	1.40	5.00	100	1.1089	6.3258	0.4287	25.401	101	1.1244	5.8410	0.4288	23.953	49.354	48.796

TABLE No. 6.—Water Level Observations.

Piezometer Gauges.

1	2	3		4	5	6	7	8	
				West Piezometer.		East Piezometer.			
Date.	Number of experiment.	Time of beginning.	Time of ending.	Number of observations.	Mean reading. Feet.	Number of observations.	Mean reading. Feet.	Differences. E. piezometer reading minus, W. piezometer reading feet.	
				North Pipe.					
1894.									
September 7th, P. M.	1	1.20	3.00	46	4.3046	45	4.2909	—0.0137	
" 11th, P. M.	2	1.20	3.00	50	5.3540	50	5.3421	—0.0119	
" 12th, A. M.	3	10.00	11.40	50	4.2514	50	4.2528	0.0014	
" 12th, P. M.	4	1.20	3.00	50	5.4396	50	5.4335	—0.0061	
" 13th, A. M.	5	10.00	11.40	50	3.9089	50	3.9105	0.0016	
" 13th, P. M.	6	1.20	3.00	50	3.9096	50	3.9060	—0.0036	
" 14th, A. M.	7	10.00	11.40	50	3.8730	50	3.8742	0.0012	
" 14th, P. M.	8	1.20	3.00	50	3 8747	50	3.8735	—0.0012	
October 4th, A. M.	9	10.00	11.40	50	3.9531	50	3.9528	—0.0003	
" 4th, P. M.	10	1.20	3·00	50	4.0440	50	4.0408	—0.0032	
" 5th, A. M.	11	10.00	11.40	50	4.2414	50	4.2368	—0.0046	
" 5th, P. M.	12	1.20	3.00	50	4.2392	50	4.2345	—0.0047	
" 6th, A. M.	13	10.00	11.40	50	4.2508	50	4.2559	0.0051	
" 6th, P. M.	14	1.20	3.00	50	4.2481	50	4.2503	0.0022	
	Mean							—0.0027	±0.00097
	Vernier correction							+0.0008	
	Correction for zero of scale							= —0.0019	

SOUTH PIPE.

1894.									
October 18th, P. M.	15	1.20	3.00	50*	....	50*	....	....	
" 19th, A. M.	16	10.00	11.40	208	5.0639	195	5.0658	0.0019	
" 19th, P. M.	17	1.20	3.00	200	5.0425	200	5.0428	0.0003	
" 20th, A. M.	18	10.00	11.40	187	4.8910	194	4.8917	0.0007	
" 20th, P. M.	19	1.20	3.00	177	4.8637	204	4.8610	—0.0027	
" 30th, A. M.	20	10.00	11.40	201	3.7612	201	3.7608	—0.0004	
" 30th, P. M.	21	1 20	3.00	201	3.7598	201	3.7596	—0.0002	
November 30th, A. M.	22	10.00	11.40	50*	....	50*	....	....	
" 30th, P. M.	23	1.20	3.00	158	4.2604	201	4.2633	0.0029	
December 1st, A. M.	24	10.00	11.40	188	4.0946	199	4.0908	—0.0038	
" 1st, P. M.	25	1.20	3.00	197	4.0921	197	4.0899	—0.0022	
" 7th, A. M.	26	10.00	11.40	201	5.9003	201	5.9000	—0.0004	
" 7th, P. M.	27	1.20	3.00	201	5.7739	201	5.7704	—0.0035	
" 8th, A. M.	28	10.00	11.40	201	5.4098	201	5.4052	—0.0046	
" 8th, P. M.	29	1.20	3.00	197	5.3845	201	5.3818	—0.0027	
" 13th, A. M.	30	10.00	11.40	201	6.4096	201	6.4067	—0.0029	
" 13th, P. M.	31	1.20	3.00	201	6.3653	201	6.3638	—0.0015	
" 14th, A M.	32	10.00	11.40	201	5.8852	191	5.8831	—0.0021	
" 14th, P. M	33	1.20	3.00	198	5.8622	201	5.8601	—0.0021	
" 15th, A. M.	34	10.00	11.40	201	5.3347	198	5.3302	—0.0045	
" 15th, P. M.	35	1.20	3.00	197	5.3223	198	5.3218	—0.0005	
		Mean						—0.0015	±0.00032
		Vernier correction						—0.0005	
		Correction for zero of scale						—0.0020	

* Observations not used in obtaining mean, because they were taken at two-minute intervals instead of 30-second intervals, and are therefore of less weight than the others.

TABLE No. 6.—Water Level Observations.

Piezometer Gauges.

1	2	3		4	5	6	7	8	
				West Piezometer.		East Piezometer.			
Date.	Number of experiment.	Time of beginning.	Time of ending.	Number of observations.	Mean reading. Feet.	Number of observations.	Mean reading. Feet.	Differences. E. piezometer reading minus, W. piezometer reading feet.	
North Pipe.									
1894.									
September 7th, P. M.	1	1.20	3.00	46	4.3046	45	4.2909	—0.0137	
" 11th, P. M.	2	1.20	3.00	50	5.3540	50	5.3421	—0.0119	
" 12th, A. M.	3	10.00	11.40	50	4.2514	50	4.2528	0.0014	
" 12th, P. M.	4	1.20	3.00	50	5.4396	50	5.4335	—0.0061	
" 13th, A. M.	5	10.00	11.40	50	3.9089	50	3.9105	0.0016	
" 13th, P. M.	6	1.20	3.00	50	3.9096	50	3.9060	—0.0036	
" 14th, A. M.	7	10.00	11.40	50	3.8730	50	3.8742	0.0012	
" 14th, P. M.	8	1.20	3.00	50	3 8747	50	3.8735	—0.0012	
October 4th, A. M.	9	10.00	11.40	50	3.9531	50	3.9528	—0.0003	
" 4th, P. M.	10	1.20	3·00	50	4.0440	50	4.0408	—0.0032	
" 5th, A. M.	11	10.00	11.40	50	4.2414	50	4.2368	—0.0046	
" 5th, P. M.	12	1.20	3.00	50	4.2392	50	4.2345	—0.0047	
" 6th, A. M.	13	10.00	11.40	50	4.2508	50	4.2559	0.0051	
" 6th, P. M.	14	1.20	3.00	50	4.2481	50	4.2503	0.0022	
	Mean							—0.0027	±0.00097
	Vernier correction							+0.0008	
	Correction for zero of scale							= —0.0019	

SOUTH PIPE.

1894.									
October 18th, P. M.	15	1.20	3.00	50*	....	50*	....	....	
" 19th, A. M.	16	10.00	11.40	208	5.0639	195	5.0658	0.0019	
" 19th, P. M.	17	1.20	3.00	200	5.0425	200	5.0428	0.0003	
" 20th, A. M.	18	10.00	11.40	187	4.8910	194	4.8917	0.0007	
" 20th, P. M.	19	1.20	3.00	177	4.8637	204	4.8610	−0.0027	
" 30th, A. M.	20	10.00	11.40	201	3.7612	201	3.7608	−0.0004	
" 30th, P. M.	21	1 20	3.00	201	3.7598	201	3.7596	−0.0002	
November 30th, A. M.	22	10.00	11.40	50*	....	50*	....	....	
" 30th, P. M.	23	1.20	3.00	158	4.2604	201	4.2633	0.0029	
December 1st, A. M.	24	10.00	11.40	188	4.0946	199	4.0908	−0.0038	
" 1st, P. M.	25	1.20	3.00	197	4.0921	197	4.0899	−0.0022	
" 7th, A. M.	26	10.00	11.40	201	5.9003	201	5.9000	−0.0004	
" 7th, P. M.	27	1.20	3.00	201	5.7739	201	5.7704	−0.0035	
" 8th, A. M.	28	10.00	11.40	201	5.4098	201	5.4052	−0.0046	
" 8th, P. M.	29	1.20	3.00	197	5.3845	201	5.3818	−0.0027	
" 13th, A. M.	30	10.00	11.40	201	6.4096	201	6.4067	−0.0029	
" 13th, P. M.	31	1.20	3.00	201	6.3653	201	6.3638	−0.0015	
" 14th, A. M.	32	10.00	11.40	201	5.8852	191	5.8831	−0.0021	
" 14th, P. M.	33	1.20	3.00	198	5.8622	201	5.8601	−0.0021	
" 15th, A. M.	34	10.00	11.40	201	5.3347	198	5.3302	−0.0045	
" 15th, P. M.	35	1.20	3.00	197	5.3223	198	5.3218	−0.0005	
Mean								−0.0015	±0.00032
Vernier correction								−0.0005	
Correction for zero of scale								−0.0020	

* Observations not used in obtaining mean, because they were taken at two-minute intervals instead of 30-second intervals, and are therefore of less weight than the others.

TABLE No. 7.—Water Level Observations.

Tube Piezometer Gauges.

1	2	3		4	5	6	7	8	
				West Tube Piezometer.		East Tube Piezometer.			
Rate.	Number of experiment.	Time of beginning.	Time of ending.	Number of observations.	Mean reading. Feet.	Number of observations.	Mean reading. Feet.	Differences. E. piezometer reading minus. W. piezometer reading feet.	
North Pipe.									
1894.									
September 7th, P.M.	1	1.20	3.00	50	4.2924	50	4.2865	—0.0059	
" 11th, P.M.	2	1.20	3.00	50	5.3512	50	5.3389	—0.0123	
" 12th, A.M.	3	10.00	11.40	49	4.2626	50	4.2536	—0.0090	
" 12th, P.M.	4	1.20	3.00	50	5.4413	50	5.4295	—0 0118	
" 13th, A.M.	5	10.00	11.40	50	3.9197	50	3.9080	—0.0117	
" 13th, P.M.	6	1.20	3.00	50	3.9119	50	3.9010	—0.0109	
" 14th, A.M.	7	10.00	11.40	49	3.8847	50	3.8761	—0.0086	
" 14th, P.M.	8	1.20	3.00	47	3.8834	50	3.8756	—0 0078	
October 4th, A.M.	9	10.00	11.40	50	3.9557	50	3.9466	—0.0091	
" 4th, P.M.	10	1.20	3.00	50	4.0442	49	4.0376	—0.0066	
" 5th, A.M.	11	10.00	11.40	50	4.2382	50	4.2328	—0.0054	
" 5th, P.M.	12	1.20	3.00	50	4.2333	50	4.2253	—0.0080	
" 6th, A.M.	13	10.00	11.40	50	4.2590	50	4.2517	—0.0073	
" 6th, P.M.	14	1.20	3.00	50	4.2548	50	4.2534	—0.0014	
	Mean	....	....	....	....	....	....	—0.0083	±0.00053

SOUTH PIPE.

1894.									
October 18th, P.M.	15	1.20	3.00	51	5.2234	50	5·2128	−0.0106	
" 19th, A.M.	16	10.00	11.40	50	5.0639	50	5.0585	−0.0054	
" 19th, P.M.	17	1.20	3.00	50	5.0375	50	5.0312	−0.0063	
" 20th, A.M.	18	10.00	11.40	50	4.8869	50	4.8796	−0.0073	
" 20th, P.M.	19	1.20	3.00	50	4.8516	50	4.8452	−0.0064	
" 30th, A.M.	20	10.00	11.40	50	3.7623	50	3.7592	−0.0031	
" 30th, P.M.	21	1.20	3.00	50	3.7633	50	3.7569	−0.0064	
November 30th, A.M.	22	10.00	11.40	45	4.3253	50	4.3151	−0.0102	
" 30th, P.M.	23	1.20	3.00	45	4.2652	50	4.2555	−0.0097	
December 1st, A.M.	24	10.00	11.40	45	4.0880	50	4.0852	−0.0028	
" 1st, P.M.	25	1.20	3.00	45	4.0848	50	4.0826	−0.0022	
" 7th, A.M.	26	10.00	11.40	45	5.9025	50	5.8938	−0.0087	
" 7th, P.M.	27	1.20	3.00	45	5.7721	50	5.7650	−0.0071	
" 8th, A.M.	28	10.00	11.40	45	5.4064	50	5.4011	−0.0053	
" 8th, P.M.	29	1.20	3.00	45	5.3861	50	5.3765	−0.0096	
" 13th, A.M.	30	10.00	11.40	90	6.4111	50	6.4082	−0.0029	
" 13th, P.M.	31	1.20	3.00	95	6 3764	50	6.3627	−0.0137	
" 14th, A.M.	32	10.00	11.40	47	5.8824	50	5.8789	−0.0035	
" 14th, P.M.	33	1.20	3.00	47	5.8632	49	5.8543	−0.0089	
" 15th, A.M.	34	10.00	11.40	50	5.3299	50	5.3296	−0.0003	
" 15th, P.M.	35	1.20	3.00	46	5.3214	50	5.3148	−0.0066	
	Mean	....	....	....	....	....	....	−0.0065	±0.00049

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AMERICAN SOCIETY OF CIVIL ENGINEERS.
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PAPERS.

BANK REVETMENT ON THE LOWER MISSISSIPPI.

By H. St. L. Coppée, M. Am. Soc. C. E.

To be Presented February 19th, 1896.

The following paper is written for the purpose of giving in logical sequence the operations of engineers on the lower Mississippi River in dealing with the problem of bank protection, as derived from personal knowledge and experience and information on the subject gleaned from the scattered appendices in the reports of the Chief of Engineers of the United States Army. Much valuable engineering knowledge is buried in these executive documents that can be resurrected with great difficulty, as the different members of one subject have often been interred in many volumes, frequently covering a considerable range of years.

By the lower Mississippi is meant that portion of the river from Cairo to the mouth, which is, strictly speaking, an alluvial stream, its waters charged with sediment received from its tributaries and taken from its crumbling banks, the amount varying with its course from bend to bar. It flows through an alluvial plain, in great part formed by its own agency.

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

It is the purpose of the author to give a brief description of the different kinds of revetments used to protect the banks of the river from erosion, their cost, manner of construction, and the results obtained by their use. The relative value of different methods of river improvement, the success and cost of certain projects or lines of procedure as a whole, will not be discussed. The author will confine himself strictly to the details of construction and their evolution from the cruder methods of twenty years ago to the more advanced practice of the present day.

It is a well-known fact that revetment made of brush, cane, straw, etc., has been used in Europe and Asia for the protection of river banks and levees for many years, and it is therefore not a novelty; but the manner in which it is constructed differs very considerably, even in this country, varying from the log mattress of the sea wall to the closely woven fascine revetment of the non-tidal stream.

It is customary in protecting the banks of a river to use, if possible, the material found in most abundance and procured most economically in the immediate vicinity of the improvement. On the lower Mississippi the foreshores, bars and low-lying lands are covered to a great extent with an abundant growth (thousands of acres) of willow and cottonwood saplings that can be woven into mattresses with great facility, when cut and shipped to the working ground. Stone, though not so plentiful, is obtained at reasonable prices from the quarries of the bluff formation of the Mississippi, the foot-hills of the Ozarks on White River and other portions of Arkansas, and also from Alabama, but a few hours distant by rail from the lower river; and as ballast from vessels in the port of New Orleans. The other articles of which the revetment is manufactured—spikes, wire, cable, manilla rope, staples, etc.—are purchased generally in a northern market. The labor employed is procured from the floating white population of the country and the colored residents of the southern States bordering on the Mississippi.

The purpose of the revetment, as before stated, is to prevent the bank caving (which, without protection, is constantly occurring on the concave side of the river), and thus reduce the load of sediment carried to the bar, preventing its rapid growth; to maintain a normal width and depth in the bends, and to protect valuable property in danger of being destroyed by the constant action of the currents.

The difficulty of constructing and maintaining works of this character on the Mississippi River is very great, owing to the excessive variation in the height of water surface and the volume of discharge, the great depths, swift and changing currents in the caving bends, and the short season when the water is at a stage sufficiently low to admit of building and sinking mattresses.

The methods at first adopted on the lower Mississippi to keep the banks from caving were similar to those in use on the Missouri, which, though a smaller stream, is subject to much the same conditions of flow and bed. The first revetment used on the lower river was purely local and for the protection of property, and not with a view to bettering navigation or in any way improving the river for the purposes of transportation. Prior to 1878, as the river at Memphis had been encroaching on the shore in the vicinity of Wolf River and below, threatening the destruction of valuable business houses and other property, an appropriation was granted by Congress to be expended under the direction of a United States engineer officer, for the amelioration of these very serious conditions.

At Vicksburg, in the spring of 1876, a cut-off occurred, leaving the city on the bank of a lake, the west side of the new channel having rapidly caved away, thus carrying the navigable water farther and farther from the town wharves and landing. To check this action, on the recommendation of a board of United States engineer officers, Congress allotted funds for the promotion of a project of improvement having as an essential factor the prevention of the bank caving at Delta Point.

At New Orleans a project was formulated by the United States engineer officer in charge of that district for the protection of the wharves threatened by the scouring action of the water, the purpose being to build a timber bulkhead in about a line with the outer edge of the wharves, and also to carpet the slope below that line with mattresses. In 1878 money was obtained from Congress and the next year work was commenced. The methods employed by Captain Eads on the jetties at the mouth of the river will not be considered, as that work consisted in the building of new (artificial) banks rather than the protection of the natural ones, and also as the conditions directly at the gulf are so dissimilar to those existing above. The lower reach at the jetties partakes somewhat of the character of a tidal estuary, a

well as a sedimentary river, though no tidal inflow is perceptible at the surface.

The lower Mississippi River flows through a low-lying land subject to inundation, composed for the most part of sedimentary deposit formed by the river itself, though undoubtedly having its origin at some points at a period remotely antecedent to the fluvial existence. The material as exposed in the caving banks is found generally in horizontal strata of varying thickness and consistency, no definite order being maintained, the position of each layer having been determined by the special locality, and its location relative to the current of the river during its formation. A section of the bank at Delta Point above low water shows a thick top layer of soil; then buckshot; then sand; then a thin layer of clay and buckshot; then sand; then yellow clay; then sand, underlaid by a thick layer of blue clay reaching to low-water level. At some points the section is mainly sand; at others, the major portion is buckshot, the latter being a tenacious black clay, which, if continuous and not intersected by layers of sand or lighter material, would withstand the action of the water almost as successfully as rock. This indicates how impossible it would be to modify the form of revetment to suit each arrangement of strata, changes in which may occur in less than 100 ft. length of bank.

The object has been to endeavor to construct all revetment sufficiently strong to protect the weakest material. The position of the strata and the drainage of the back-lying lands are also potent factors in the problem of improvement by revetment, as the lighter strata, sand, etc., act as drains for the ground-water at low stages, causing much damage by sloughing.

The position and extent of the soft strata in the bank, the drainage of the adjacent land, the degree of curvature of the bend, the slope and velocity of the water, the position and depth of the channel, the kind of growth on the land, and the stage of the river, determine the extent, rapidity and kind of caving. Most of the bank caving occurs at medium high stages of river, and is specially extensive on a rapid decline after a continued high water. The channel of the river in the bends probably deepens or scours at most points during the high water and rising river, when the velocity is greatest; but the actual caving of the bank does not as a rule take place until the support of he water has been taken away.

At some points the bank caves at all stages, this action being caused principally by abrasion; while at others, the combined action of the seep or drainage water through the soil and the undermining of the foot of the slope cause what is termed sloughing. This kind of caving is most difficult to contend with, the bank often sliding out in great sections, carrying with it willows and stone and necessitating a re-adjustment of the work for some distance above and below. At the bank-full stage in many places the thread of maximum velocity occupies a position approaching more nearly the center of the stream, thus decreasing the scouring action at the sides.*

Vicksburg Harbor, 1878 to 1881.—The first work at Delta Point, opposite Vicksburg, consisted of the revetment of the bank below medium low water, it being expected that the upper bank would be graded to a gentle slope by the action of the water, not needing other protection.

The plant, labor and materials, with the exception of rock, used in the early construction was furnished by the Government, the rock

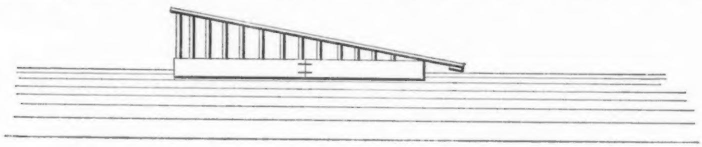


Fig. 1.

being contracted for. The protection work consisted of willow mattresses 50 ft. wide by 150 ft. long, constructed on floating ways. An attempt was made in November, 1878, to use stationary land ways, but they caved into the river, and the method was abandoned. The floating ways or barge on which the mattress was manufactured consisted of two coal boats, each 165 ft. long, with the gunwales cut down, placed parallel to each other and bolted together (see Fig. 1). On them the ways proper were erected, having inclined skids 6 ft. apart running across the barge, supported at intervals of 4 ft. by posts. The upper end of the skids or runs was 8 ft. above the gunwales, the lower end resting on the barge. This inclination proved too slight for starting the

* A recorded instance of bank caving occurred in Gouldsboro Bend, New Orleans Harbor, December 14th, 1887. Just above a spur dike, a mass of earth in the shape of a semi-ellipse in plan, having an axis of 300 ft. and semi-axis of 60 ft., moved downward and outward into the river. The movement was regular and at the rate of about ½ in. per minute. The bank was quite steep before the caving. The cause was a pond on the bank from which the water seeped into the river.

mattress, and had to be increased. The runs extended 6 ft. beyond the edge of the barge, resting in the water when the weight of the mattress was on them. The timbers of the framework were 4 x 6-in. cypress, the runs being of long leaf pine. Stringers were fastened below the runs at the lower end, to strengthen them. On this barge a mattress 50 x 175 ft. could be constructed

Willow brush and poles were obtained from a bar in near proximity to the work and placed on barges. When ready to manufacture the mat, these barges were towed alongside of the mattress ways, and the material taken from them as needed, the mat barge being fastened to the shore, and the mattress barges to the material barges by manilla rope. The laborers on the material barges passed the brush and poles to the mat-builders on the mat barge, as required. The mattress construction consisted in first placing longitudinal stringers made of willow or cottonwood poles 6 ins. in diameter at the large end, fastened

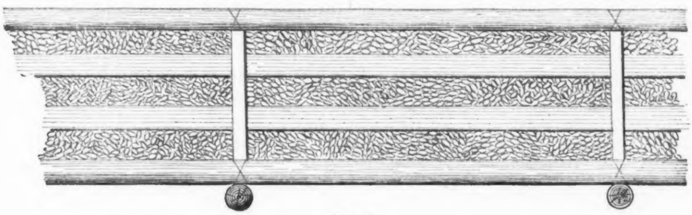


FIG. 2.

together with wire and spikes, 8 ft. apart on the runs, each stringer stretching along the barge the full length of the mattress. In a mat of 50 ft. width there were about seven stringers. Across these and on top of them were then placed a set of transverse stringers of the same dimensions, also 8 ft. apart, fastened to the longitudinal system at the intersections with wire and spikes. At the intersections were also inserted, in a vertical position, pins of swamp hickory 1 in. in diameter and 3 ft. long.

On top of this framework and between the pins were then laid five layers of small willow brush, each layer at right angles to the one above and below, until a thickness of 2 ft. was obtained (see Fig. 2). On this brush was placed a set of transverse stringers 8 ft. apart, in the same manner and of the same dimensions as those below. The upright pins were let into these stringers and secured by wedges and nails, thus connecting the upper and lower system of poles. No. 12 wire was

also used at the intersections to connect the top and bottom frames, adding strength to the bond.

When the mattress was completed, ropes were fastened to it in such a manner as to be readily freed by toggles when on the bottom. Then it was launched from the ways into the water and towed to the part of the bank to be revetted. A large coal boat bottom was used as a mooring barge, to which the mattress was fastened by lines, the mooring barge being held in position by shore lines (as shown in Fig. 3); the mat had independent lines to the shore, that could be released by trip toggles after sinking. When in position and ready for sinking, sufficient rock was thrown from the mooring barge and small stone flats, 30 ft. long by 12 ft. wide, to cause it to settle to the bottom. A steamboat was constantly employed in placing the barges, towing, etc.

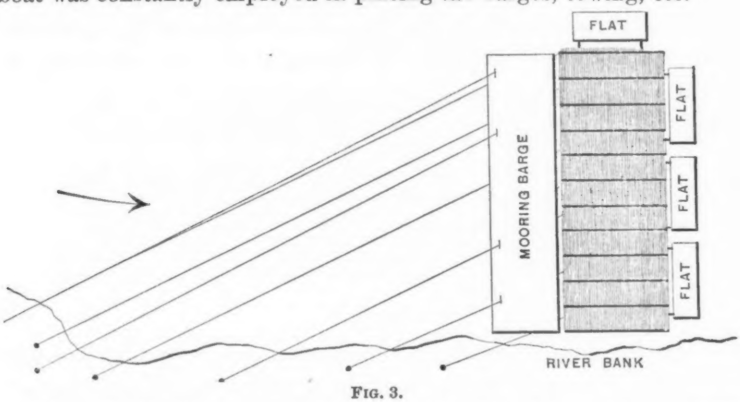


FIG. 3.

These first mattresses extended from about the low-water line 150 ft. down the subaqueous slope. One could be made and sunk in a day with the untrained labor and crude appliances, and under the unfavorable conditions of weather and river stages. In 1879 a great number of these mattresses were sunk successfully at Delta Point. The matbuilders became so proficient that as many as four mats were sometimes made and sunk in one day. A considerable reach of river front was thus revetted. In some instances, the depth of the water at the outer edge of the mat was 80 ft.

Experiments were then made with floating screens, similar to those used by Colonel Suter, U. S. A., on the Missouri, but they proved very unsatisfactory.

The local engineer gives the cost of revetment with these early

mats as about $18 per lineal foot of bank ($12 per square)* under favorable conditions. It must be remembered that this only represents subaqueous work, the upper bank not being improved in any manner. In 1880 it became apparent that the protection of the subaqueous bank only, leaving the upper slope exposed to the destructive action of the currents, was bad practice, and that some method would have to be adopted for its preservation. This was accomplished by grading the upper bank to a slope of about 45° with shovels, from about the low-water line to the top, and placing on this uniform slope a revetment composed of willow fascines laid to a thickness of about 8 ins., having on top transverse poles which were fastened to the ground by wires to deadmen, thus holding the willows in place. A deadman is a beam set horizontally in the ground forming an eye or loop as shown in Fig. 4. No rock was used on this revetment.

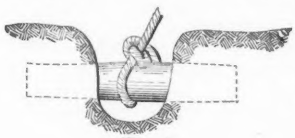


FIG. 4.

In 1881 it was proposed to institute a new method of bank grading which had been successfully applied on the Missouri, viz., the removal of the material of the upper bank by means of a jet of water. For that purpose a fire pump was placed on a barge 16 ft. wide by 98 ft. long by 3½ ft. deep; the pump being of the Dayton cam make, with cylinders 16½ x 18 ins., and water plungers 9 ins. in diameter, and with two 4-in. discharge pipes. On the barge was also a boiler 42 ins. in diameter by 20 ft. long, with two 14-in. flues. The total cost of the grader complete was $3 679. This machine was not used during the season of 1881, owing to adverse conditions of river stage, etc., the work, as before, being confined to mat-building; the method of mat construction was entirely changed, the pole frames at the top and bottom and the hickory pins, which were found to be weak, being entirely dispensed with, and in their place a wire netting substituted, fastened by wire stitches made through the mat.

Before giving the details of construction, it will be well to describe the mattress boat on which this form of revetment was built. It consisted of two barges 20 ft. wide, 150 ft. long and 3 ft. deep (see Fig. 5), with cypress gunwales 8 ins. thick at the bottom and 6 ins. at the top, with yellow pine bottoms 2½ ins. thick; with a rake at one end

* By a square is meant 100 sq. ft.

allowing an overlap on the shore for connecting the mat to the revetment above water. The barges were rigidly fastened to each other by beams 8 x 18 ins. in section and 30 ft. long, a 9-ft. space being left between. This space was spanned by 4 x 6-in. sills, at intervals of 5½ ft., which supported the posts, 4 x 6 ins. and 6½ ft. apart, on which the runs rested. The runs or skids were 4 x 6-in. cypress, beveled on the upper side, and were 5½ ft. between centers. The top of the runs on the high side was about 13 ft. above the water, and on the low side they rested in the water about 8 ft. outside of the gunwales. There was a break in the run slope at 37 ft. from the top, the upper grade being about 6½ to 1, and the lower 3½ to 1. The lower ends of the runs rested upon a 4 x 10-in. guard sill, running parallel to the barge, to which they were bolted. A floor 4 ft. below the top of the runs enabled men to work under the mat; it also acted as a brace to the posts. A platform 8 ft. wide projecting from the high side of the ways extended the whole length of the barges. On this platform was a drum on which

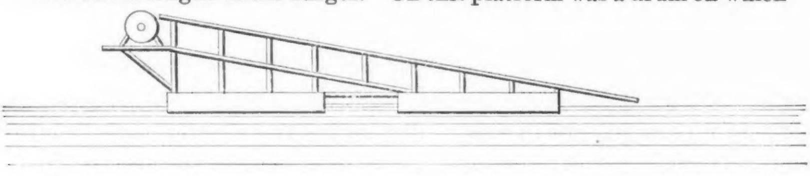


FIG. 5.

was formed the wire netting. It consisted of a wooden frame 12 ft. in circumference, with a 6 x 6-in. wooden shaft. On this circumference were fitted wrought-iron bands 1½ ins. wide and ¼ in. thick. These bands were in pairs, 6 ins. apart, each pair 2 ft. between centers. Around the circumference of the bands were nibs of round iron ½ in. in diameter, 1¼ ins. high, and riveted to the band. The nibs were in pairs also, 1 in. apart, and 12 ins. between centers of pairs. The nibs were exactly opposite each other on the different bands, making continuous lines along the drum.

In making the netting a No. 8 wire was placed along the drum between the nibs, then two transverse wires were placed between the bands, one over and the other under the longitudinal wire. Before the drum revolved, bringing a new set of nibs to the top, a 2-ft. mesh was formed by twisting the cross wires firmly around the longitudinal wire with a steel pin.

In constructing the mattress, longitudinal poles were first laid 8 ft.

apart, not for the purpose of strengthening the mat, but because it was found impossible to launch it without them. On these poles was placed the wire netting of the same dimensions as the proposed mat. On the netting was placed the brush in three layers to the thickness of 1 ft. Then the willows were sewed to the wire netting with No. 12 wire, the seams being made 4 ft. apart, and in lines parallel with the length of the mat. In taking the stitches one man stood on the top of the mat, and another on the platform under it. The lower man carried a coil of wire, playing it out in the line of the proposed seam. The man above carried a ⅝-in. iron needle, 3 ft. long, having an open slot in one end and a bend in the other. He thrust his needle through the mat at intervals of 2 ft., catching up the wire from beneath in the slot and pulling it to the upper surface, where a wooden toggle was placed in the bight of the loop and fastened to it by a staple, holding it temporarily in place until the entire seam was made, when a top wire was run through each loop, and a turn taken around each loop, thus forming the completed seam. It was proposed at first to build continuous mattresses of this form, but for some cause the purpose was abandoned, and mattresses 50 x 150 x 1 ft. were constructed instead. Cross rows of poles were wired to the top of these mats, to keep the rock ballast from rolling off. The operation of sinking was similar to that employed for the pin and pole mats of 1878.

Permeable floating screen revetments were experimented with again, but the results were not satisfactory, the high water carrying them away. They proved serviceable on the Missouri River, but on the lower Mississippi they were entirely too light in construction to be of permanent value.

Memphis Harbor, 1878.—The work for the protection of the river bank at Memphis was in progress at the same time as that at Delta Point, Vicksburg. In 1878, owing to the prevalence of yellow fever, but little was accomplished, but the next year a full and successful test was made of the revetment method of improvement for that locality. Neither the appliances for manufacturing the mat nor its construction were similar to those adopted at Delta Point. Stationary mattress ways were formed by cutting the bank to an angle of 40° and placing in the slope posts 5 ft. apart, on which rested 4 x 6-in. stringers rounded on top, and drift-bolted into the posts. In the mat construction various designs were tried. At first four frames of willow poles

were used, the first frame at the bottom being formed by placing poles 4 ft. apart, and other poles transverse to them at the same interval. These poles were fastened together by ¾-in. oak pins. On this framework was placed a layer of willows; then another framework in 12-ft. squares; then a second layer of willows, and another framework in 12-ft. squares; then a third layer of willows, on top of which was placed the last frame of poles 4 ft. apart, as in the bottom frame. Each intersection was firmly pinned through the mat, and fastened also by No. 12 annealed wire, thus forming a very thick mattress. This structure was found to be unnecessarily heavy and thick and was therefore changed, the two 12-ft. pole frames being dispensed with, and only two frames used, one at the bottom and one at the top, with poles 4 ft. apart pinned every 8 ft. by 1-in. oak pins, and well wired. These mats were sunk in water 80 ft. in depth at some points. The sinking was accomplished in a manner similar to that followed at Delta Point. The stone at this locality cost $2 45 per cubic yard on barges at the work. Up to June, 1880, 1 300 lin. ft. of bank had been protected at this point, and in addition to the subaqueous work, upper bank revetment was constructed of the same design as the mattress, making a total of 2 385 squares of revetment. The distribution of material in this work is shown in Appendix A. Up to 1882, 3 125 lin. ft. of bank had been protected, and the caving was reported at least temporarily stopped.

In 1881 the pin and pole method of mat construction was abandoned here, and a wire frame substituted. No. 10 annealed wires were laid longitudinally and 6 ft. apart on the same ways used for the old mats, the end of each wire being turned about a binding pole and held temporarily by a strong stake. At right angles to these wires and 6 ft. apart others were also fastened at the ends to binding poles and temporary stakes. At the intersections these wires were fastened by other wires of sufficient length to reach well up on stakes to which they were temporarily attached. These stakes were driven into the ground and reached an elevation 2 ft. above the mat, preventing it from sliding off the ways during construction. On the bottom wire frame thus formed, willow brush in four layers was laid to a thickness of 18 ins., and over it a wire frame similar to that below was placed, and fastened to it through the mat by the short wires that were temporarily held up by the stakes. At the ends the wire frames were fastened to a sys-

tem of poles which formed, when joined together, a strong selvage around the mat. These new mats were 125 x 50 ft. and 18 ins. thick. They were launched from the ways and sunk in a manner similar to the others, with the exception that a portion of the ballast was gravel in sacks tied to the mat and loose. This proved more economical at first than stone, but was neither so satisfactory nor so permanent, being too light to resist the force of the current. During the same season, 1881, a part of the upper bank was revetted in the following manner: First, brush was laid on the bare slope in three layers to a thickness of 18 ins.; then wire was placed over it and fastened to specially formed stakes, which were driven into the ground, stretching it tight over the brush, thus binding it down; then the brush was given a good covering of stone. About 900 squares of this mat and 130 squares of upper-bank revetment were constructed, with the expenditure of material shown in Appendix A.

New Orleans Harbor.—The early revetment work at New Orleans was to prevent the wharves from being washed into the river. In 1878 the project consisted of the erection of a bulkhead built of pairs of piles, the piles in a pair being 3 ft. apart, and each pair 6 ft. from the center of the other pair, all connected at the top and low-water line,* and of the sinking of cane mats along the subaqueous slope.

The mattresses were constructed of fishpole cane, being, when completed, 2 ins. thick, 25 ft. long and 24 ft. wide. At first they were made by hand, two galvanized iron wires being used as the warp, woven with the shoemaker's stitch, one wire running over one cane, and under the next, over the third, under the fourth, and so on, the other wire being reversed, thus crossing the first and forming loops, but being fastened only at the end canes. A split was made in each cane through which it was hoped sediment would pass and help to sink the mat. Seven double strands of wire about 4 ft. apart were used for each carpet. Afterward a loom was used, and spun yarn substituted for wire.

When eight of these small mats or carpets were completed, they were taken to the floating ways and placed thereon and connected, making a mattress 200 ft. long by 24 ft. wide. At first they were ballasted with old iron boiler tubes filled with sand and fastened to them. They were ballasted on the floating ways, the ways being after-

* Behind these piles and up to the low-water line were to be piled brush fascines, forming a brush wall.

ward moved up to the line of piling forming the bulkhead, and the mattress fastened to it by iron rings. The ways were then pulled out in the river by a tug, and the mat thus launched was sunk in place on the bottom. Stone was not used, as it was deemed necessary on this steep subaqueous slope to fasten the ballast to the mat to prevent its sliding off. The cost of a square of this cane carpet was $12 87. In 1879, owing to the change from hand weaving to loom work, and the experience gained by the employees during the first season, the cost was reduced to $9 88 per square.

Seventy-four carpets were made, averaging 200 x 26 ft.; 1 116 lin. ft. of bank were revetted, and about 1 496 squares of river bed covered, at a cost, as stated, of $9 88 per square, and $13 38 per lineal foot. The officer in charge reports it was suggested that shrimp, which are known to eat the oakum out of the seams of vessels lying in port, might attack the spun yarn used in construction of the mats, but experiments indicated that there was nothing to be feared from this source.

In 1880 a contract was entered into for the sinking of mattresses at 65 cents per square yard, or about $7 22 per square. Anchorage piles were driven as before, and cane mattresses 200 x 70 ft. sunk with sand bags. The mats were made of 40 sections, 14 x 25 ft. each, sewed together. For mattress construction, a float was used formed of eight coal barges fastened together, supporting launching ways, the dimensions over all being 170 x 206 ft The skids had a slope of 7½ ft. in 170 ft.

An attempt was made to construct and sink a mattress 140 x 200 ft., but it proved a failure, so the ways were changed for mattresses 84 x 200 ft., and the slope of skids increased to 8 to 1.

For the purpose of mooring the mattress in the desired position preparatory to sinking, three flatboat gunwales were used, so placed as to form a right-angled triangle with the altitude along the piling and the base normal to the shore, the diagonal barge being supposed to fend off drift. To the barge forming the base of this triangular mooring plant, the mattress was fastened, and, after launching, also to the ways. It was thus sunk with guides on three sides, with lines to the gunwales above, to the ways barge below, and to rings on the piling of the bulkhead. After sinking about five of these mattresses, the contractor's plant was destroyed by drift, and the work abandoned. Work was commenced again under a new contract later in the same season, and

27 cane mats 200 x 84 ft. sunk successfully, covering about 2 268 lin. ft. of bank.

In 1881 a board of officers was appointed by the Secretary of War to consider the value of revetment placed up to that time, and the desirability of a change in the project and methods of construction.

After a survey of the locality had been made and the subject of improvement thoroughly studied, the board submitted a report condemning the plan on which the work was based and the methods of construction adopted, as ineffectual in accomplishing the desired end, and recommended that changes be required by the city government in the construction of wharves by companies and individuals, and also that at certain points mattresses be sunk 400 ft. wide, made of brush, not cane poles, costing about $28 per lineal foot. A project based on the report of this board of engineer officers was adopted by the Mississippi River Commission, but no further work was undertaken until the season of 1883.

It may be well to state here, for those not familiar with the Mississippi River and its phenomena, that below Baton Rouge, which is 1 000 miles from St. Louis, or 820 miles from Cairo, its general appearance, physical features and properties and mechanical forces are quite different in degree from those existing above. The slope is less, the average depth much greater, the width less. No obstructive bars or crossings occur in this portion of the river. The caving is comparatively slight. The range from low to high water at New Orleans is about one-third that at Arkansas City. The current velocity at low water is very low, and the radii of the bends are greater.

With such a radical difference in the agencies of bank destruction it can readily be seen that a difference in means for protection will follow. The subaqueous work is placed with greater facility and a much lighter form of revetment is practicable and efficacious. Interrupted or broken revetment and dikes with unprotected intervals produce better results than in the upper river, where the range of water level, currents, depths and instability of the banks are so much greater.

Early Work of the Mississippi River Commission.—In 1879 Congress provided for the appointment of a Mississippi River Commission, composed of three United States engineer officers, an officer of the Coast and Geodetic Survey and three civilians, whose duty should be to obtain

such data as were deemed necessary, on which to base a general project for the improvement of the river from Cairo to the mouth, and execute the same with funds appropriated for the purpose. By 1881 this commission had accumulated a vast amount of information, had made an exhaustive study of the problem, and formulated a project for improvement, which was inaugurated in 1882.

The plan adopted contemplated two distinct classes of work.

First.—Permeable dikes, screens, etc., closing chutes and side channels, thus contracting or narrowing the river in the wide and shallow reaches, and making it conform to a normal low-water section.

Second.—Bank protection work, brush mattresses, and stone riprap to hold the shore or river bank intact, preventing caving and the forming of bars below. To quote the report of the commission to the Secretary of War, dated November 25th, 1881:

"The bank revetments are intended, not only to stop the constant, and in some localities very rapid, enlargement produced by erosion and caving of concave bends, but in addition thereto to check the growth of bars and shoals below, by accretions supplied directly therefrom.

"The process of laying this revetment will vary greatly in different localities, but will commonly, or at least in many cases, consist in first freeing the banks of snags, stumps and brush, and then placing a mattress * * * upon that portion of the slope extending from deep water to a few feet above the water level, and weighting it with sufficient riprap stone to hold it in place.

"The revetment to be afterwards completed by grading the bank above the water level to a proper slope with streams of water under high pressure, after the manner commonly followed in hydraulic mining, and laying thereon a supplementary mattress, overlapping the one previously laid, and extending up to the crest of the bank. * * * Whenever it may be deemed safe to omit the mattress on the upper part of the slope, and place the stone covering directly on the bank, that course will be pursued."

Two reaches of river were at first selected for improvement, viz., Plum Point above Memphis, 40 miles long, and Lake Providence below Greenville, 35 miles long. The work of harbor improvement on the lower river, in progress under the United States engineer officers, was also transferred to this commission.

Radical changes had to be made in the general design of protection work, to make it applicable to long reaches of rapidly caving banks. The harbor mattresses, though of temporary value, could not be said

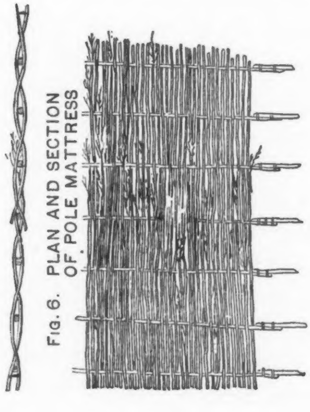


FIG. 6. PLAN AND SECTION OF POLE MATTRESS

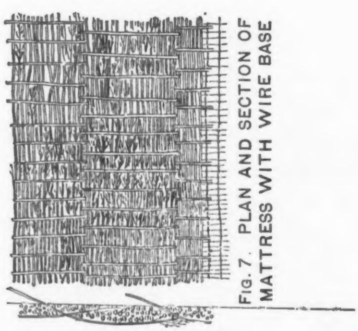


FIG. 7. PLAN AND SECTION OF MATTRESS WITH WIRE BASE

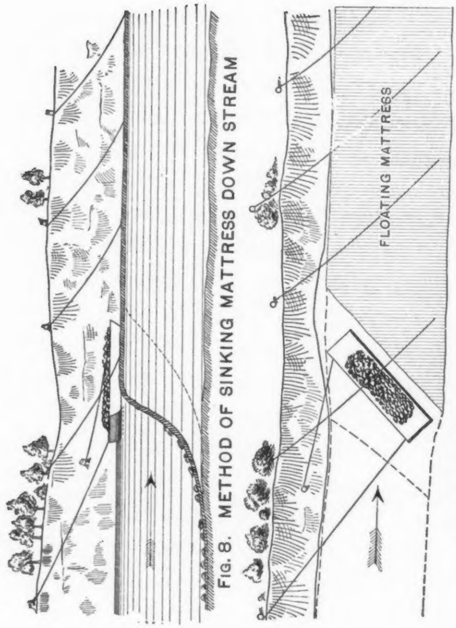


FIG. 8. METHOD OF SINKING MATTRESS DOWN STREAM

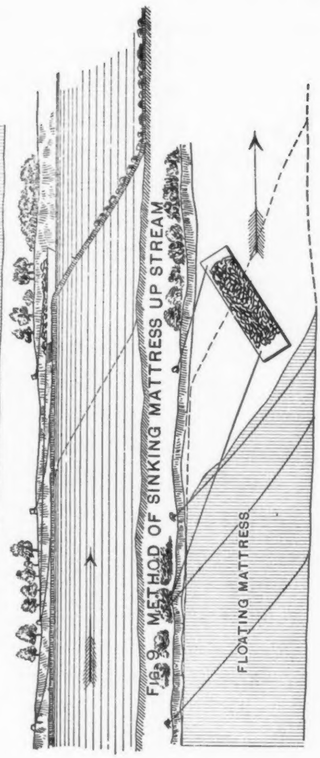


FIG. 9. METHOD OF SINKING MATTRESS UP STREAM

to have given permanent protection, because of their small size and detached condition when in place on the subaqueous slope. For long reaches they were very expensive.

The first considerable change was made by increasing their width to three times that formerly attained, and constructing and sinking them in continuous stretches of from 500 to 2 000 ft. Where timber skirted the bank, much clearing and grubbing had to be performed, and in many places great numbers of snags had to be removed by boats built for that special purpose. The thickness of the revetment was very much decreased and the strength much increased by means of iron rods, cables, etc.

The first mattresses used by the Mississippi River Commission on the Plum Point Reach were, when completed, much the same in general form as those constructed at Delta Point in 1881, though the manner of making them was different. They were constructed on a specially designed machine barge and had for their foundation a wire netting of No. 8 and No. 12 wire, the heavier running longitudinally up and down stream, and the lighter transversely, the distance* between the former being 4 ft. and between the latter generally $2\frac{1}{2}$ ft. The brush was carried by machinery operated by steam, from a brush barge, over the mat barge and deposited on the netting, where it was received by men holding hooks, who packed it close together in continuous layers. After a full shift of brush had been deposited upon the netting, brush binders were inserted with their butts into and at least 8 ft. through the netting (see Fig. 7), the tails being bent over the butts last laid and wired firmly through to the netting. The binders were placed at right angles to the brush, and wired at a point directly under the space to be occupied by the succeeding shift. These mats were continuous, ballasted and sunk in the same manner as those to be described hereafter.

A more detailed description of the wire net making machine and general construction of this mat will not be given here, as it was found to be unsatisfactory for many reasons and was soon abandoned.

Work at Delta Point, 1882–83.—In 1882 little or no bank protection was undertaken at Plum Point or Lake Providence Reach or any of the harbors except Vicksburg, where the revetment of Delta Point was vigorously prosecuted with new methods of construction. The

* See the "Report of the Mississippi River Commission," 1883, p. 371.

new mattresses were built after a plan adopted on the upper river in the vicinity of St. Louis and were termed woven mattresses. These new mats were made on the ways built for the wire-net construction heretofore described, the drums and other wire net machinery having been removed.

The mode of construction was as follows: A low-gunwale flatboat, acting as a mooring barge, 170 ft. long by 26 ft. wide, was placed with the bow to the shore and stern into the stream, being held in that position by 1½-in. manilla lines leading to deadmen on the bank and anchors in the stream above. On the lower down-stream side of this boat, and firmly secured to it by 1-in. lines, were the ways, placed with the lower ends of the runs up stream and the bow of the barge against the bank, the position of these two boats being directly over the

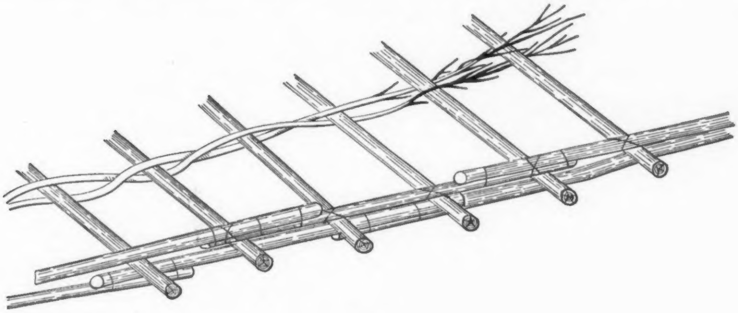


FIG. 10.

upper end of that portion of the lower slope of the bank to be revetted. The construction of the mattresses was commenced by laying 30-ft. willow poles 5 ins. in diameter at the butt across the runs and near their lower ends. These poles were lapped from 4 to 6 ft. and fastened together with No. 12 wire and four or more 6-in. boat spikes. The number of these poles depended on the width of mattress desired.

Longitudinally between the runs, about 6 ft. apart, were placed willow poles of the same dimensions, with their large ends resting on the transverse system and tightly wired and spiked to it as shown in Fig. 10. On the large ends of these longitudinal weaving poles, a third set similar to the first was laid transversely, and all three firmly spiked and wired together, thus forming a mat head or cross-selvage for the woven mat which kept it from unraveling, and acted as a strong fastening in sinking, etc.

Before commencing to weave the mattress this upper frame or head was fastened to the mooring barge by 1-in. lines. Willow brush was then woven over and under the longitudinal poles, the brush being about 30 ft. long and 3 ins. thick at the butt. The weaving was accomplished by placing the brush over one pole and under the next, over the next, and so on, until its end was reached, when it was forced down the runs and poles until the transverse poles or head was reached, to which it was made to fit tightly by means of mauls. This operation was carried on all along the ways by different gangs of men and repeated until the 30 ft. of poles, or one shift, was nearly filled with woven brush, only space enough being left on which to spike and wire other poles, thus making a continuous wooden thread on which to continue the weaving. Every 100 ft. transverse poles similar to those at the head were placed across the mat to give it strength, and longitudinal poles 12 ft. apart were bound to it on top, forming cribs to keep the rock from falling off when sunk on a steep subaqueous slope.

When one shift, or about 30 ft. in length of the mat, was woven, it covered the entire ways, and in order to continue the weaving it became necessary to remove this. To do so the lines holding the ways to the mooring barge were slackened and the ways moved down stream from under the mat, the movement being produced by the force of the current. When the latter was not sufficiently strong, the ways were moved by capstans and lines leading to anchors or the shore below. They were moved just the length of a weaving pole for each shift, until the end of the mattress was reached, when a strong frame selvage similar to the head was constructed, and the last shift launched into the river. The mattress thus floating was held at the upper end by lines to the shore and to the mooring barge, and on the shore side by 1-in. lines leading to deadmen or to trees 30 ft. apart.

These mattresses were about 400 ft. long by 144 ft. wide, the method of sinking being very similar to that employed for the earlier designs.

Rock barges were brought to the outer edge of the mat and fastened to it with lines at intervals of 10 ft. It was then loaded uniformly with rock until under a heavy strain; then, at a signal, these lines were cut, and, as it settled below the surface, the barges were pulled over it and rock thrown on it in quantities sufficient to insure

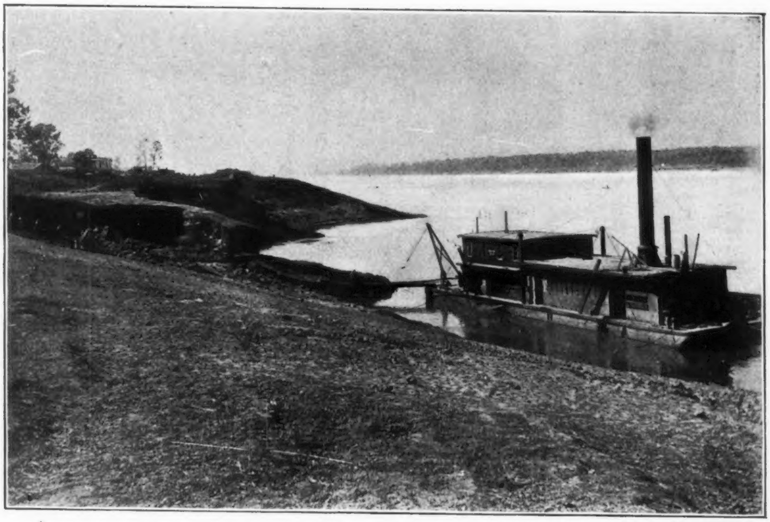


FIG. 1.

FIG. 2.

it remaining on the bottom. The number, size and position of the lines (manilla rope) depended on the force and direction of the current or currents and the depth of water. After each mattress was sunk, sharpened cottonwood piles 40 ft. long and 15 ins. in diameter were driven through the shore side, to keep it from sliding out into deep water where the slope was abrupt. From 60 to 70 ft. of this form of mattress was made per day with 52 men; 30 weaving, 6 at the mauls, 6 binding poles, 4 linesmen, and the rest on the material barges.

The mats were made to lap about 15 ft. when sunk, so that no unprotected seam would be left in the revetment. The piles used were driven about 25 ft. apart and 20 ft. into the ground, being cut off at a stage of about 10 ft. above low-water mark.

After the subaqueous slope had been covered in this manner, the upper bank was graded with shovels as in former years, but, this proving very slow and expensive, sluice grading was attempted with fair success.

A trench was first cut with a shovel to the required angle of the slope, 2¼ to 1, and in it was placed a continuous line of wooden boxes, one fitting into the other, forming a trough reaching from top of bank to water surface. A floating pile-driver containing a pump for sinking piles by water-jet was moored near the trough, and supplied its upper end with a stream of water through a hose. The material of the bank was excavated and thrown into the trough with shovels, the stream of water carrying it into the river. After grading as far as the laborers could throw the earth from the shovels, the trough was moved and the slope carried ahead. This method was also abandoned for hydraulic grading on a very much larger scale, the water being forced directly against the bank from a nozzle, to which it was supplied by very powerful pumps built for the special purpose of river-bank grading.

The grader used was designed for the Mississippi River Commission for the special purpose of bank grading. It consisted of a barge 110 ft. long by 30 ft. wide, with 6 ft. depth of hold, well braced and chained, to carry the heavy hydraulic machinery. The machinery consisted of a Blake duplex compound condensing pump. The pump had double outside plungers, each 16 ins. in diameter with 24-in. stroke. The high-pressure cylinder was 18 ins. in diameter, and the low-pressure cylinder 36 ins. in diameter, the stroke being the same as

that of the plungers, 24 ins. The capacity of the pump was 2 000 galls. per minute under a pump pressure of 160 lbs. and a steam pressure of 80 lbs. per square inch.

In connection with the low-pressure cylinder and boiler there was an air pump and condenser, which condensed the steam and heated the injection water. The steam supply was obtained from a battery of three boilers 42 ins. in diameter by 26 ft. long, with five 10-in. flues each. These pumps sucked the water from the river through two 12-in. supply pipes, and forced it through two 12-in. discharge pipes to the forward end of the boat, where they entered a 14-in. boom pipe, which was 65 ft. long and but 10 ins. in diameter at the upper end, and was held in place with accompanying stages by means of shears and steel ropes, the angle made by it with the plane of the deck being governed by a hoisting engine situated in the bow of the boat. The boom pipe had twelve 4-in. openings, with Chapman valves, to which either 4-in. or, by means of reducers, 2½-in. rubber hose was attached. At the end of each hose a 1¾-in. nozzle was used to concentrate the water for the purpose of cutting the bank. The boom pipe and stages were subsequently removed, and the hose connections made directly from the barge (see Plate III, Fig. 1). When all was ready for grading, the bow of this machine was placed against the bank, and the boom pipe and stages lowered. The hose was laid leading from the opening in the pipe to within about 8 ft. of a face which had been cut in the bank as a slope guide, and also as the only practicable way of under-cutting the steep bank and carrying forward the grade. The nozzle, which was attached to the end of the hose, rested on and was turned on a swivel, moving in an oak frame or trestle spiked to the ground. Three nozzles were used, each worked by three men. The slope was cut a little ahead at the upper end, the reason being that by so doing the water, after spending its force on the bank, on seeking a lower level ran close to the lower edge of the face, helping to under-cut it.

The direction of the stream was always kept at a greater or less angle than 90° with the face, as otherwise it would form a pocket in the bank and a water cushion to resist the pressure. It was found that a 2½-in. hose did not work advantageously, owing to the frictional resistance. A 4-in. hose and 1¼-in. nozzle gave the best results. The bank was graded to a slope of 2½ to 1. Sand and light deposit was

carried off rapidly by the force of the water, but the tougher or more tenacious materials, such as clay and buckshot, of which the Delta Point bank is in great part composed, resisted the jet for some time, but eventually was reduced. With three nozzles an average of 1 300 cu. yds. was removed per day, at a cost of about 4 cents per yard. The inequalities left in the slope were dressed down with shovels or sluice.

After the bank was made comparatively smooth and regular, continuous lines of poles, 30 ft. long by 5 ins. in diameter, well wired and spiked together, were laid on it parallel with the top, the rows being 10 to 12 ft. apart. On these were transverse poles, spiked and wired together in the same manner, in rows reaching from the top to the bottom of the slope, also 10 to 12 ft. apart. These rows were wired together at the intersections. Upon this frame, willows, 20 to 30 ft. long and 2 to 3 ins. at the large end, were laid with the butts up hill, the bushy or leafy part of the top being covered by the butts of those below, each succeeding layer of brush having its butts over the tops of the preceding one, until the water edge was reached. On the brush were placed lines of longitudinal poles directly over those in the bottom frame, and fastened to them by No. 8 wire. This revetment at the water's edge was fastened to or overlapped the mattress work if possible; otherwise a connecting mat was built to make the protection continuous from near the top of the bank to the river-bed. On the upper bank revetment rock was placed in just sufficient quantity to cover the willows.

The cost of the Delta Point work just described during the season 1882–83 is given in Appendix A. The cost of brush obtained by Government labor was $2 53 per cord; poles, 32 cents each; rock, by contract, $1 90 per yard; wire and spikes, 5 cents, and nails 4 cents per pound.

The total cost of protection, not including grading, was:

Mattress work..........	$2 90 per square.	$4 17 per lineal foot.
Upper bank revetment..	6 89 " "	5 17 " " "
	Total..........	$9 34 " " "

Including towing, grading and other expenses, the cost per lineal foot was about $14.

Work Done in 1883.—In 1883 revetment work was carried on by the Mississippi River Commission on the two principal reaches, Plum Point and Lake Providence, at Hopefield Bend, opposite Memphis, at Memphis, Delta Point and New Orleans. Practically the same methods were employed in 1883 at all points above the mouth of Red River as were used at Delta Point the year previous.

At Bullerton 100-ft. mattresses woven on a wire base were used, the willows being interlaced, as shown in Fig. 7. At Plum Point hydraulic graders were worked similar to that described. The local engineer reported 1 800 to 4 000 cu. yds. of material moved per day at a cost of 2.98 cents per yard.

Electric lights were used for night work. Mattress boats of improved make, over 200 ft. long, but practically the same design as those described, were used. Barges were employed specially adapted to the work. In fact, an entire floating plant had been constructed or purchased specially designed for revetment construction, which greatly reduced the expense and added to the strength and efficiency of the finished protection work. It had been the custom in the work previously performed to press into service anything in the form of a barge that could be used and obtained at small expense, making temporary changes in construction, rather than expend the inadequate appropriations in procuring floating property of special design.

In 1883 wire shore fastenings, instead of manilla ropes, were introduced on a small scale. Fig. 6 shows the woven mats used at Plum Point, and Figs. 8 and 9 the two methods of sinking them when continuous, one with and the other against the current. The revetment was similar to that described. The grading at Bullerton cost from 3 cents to 3.8 cents per yard, the force employed being one nozzleman and two helpers for each nozzle. These men were furnished rubber clothes by the Government.

The cost of the bank protection work on the Plum Point Reach during 1883 was as follows: Mattress work, \$6 30 per square; upper bank revetment, \$6 40 per square.

At Memphis the small mattresses were still in use, constructed on shore ways and towed to the required sinking locality. They were not made of quite the same thickness. Bank grading was still executed with shovels. The slope and revetment were thoroughly drained above low water by connecting the city drains with special wooden

culverts. The upper bank protection was slightly different from that used in former years. Wire was laid on the slope forming a 6-ft. mesh. On this was placed 6 ins. of willow brush and on top of the brush wire similar to that below, the top and bottom wire frame being sewed through the brush by separate wire, thus forming one continuous mat. This revetment was secured by placing on it stone, sand in bags and earth. The distribution of material in this work was as shown in Appendix A.

At Hopefield Bend the mattresses were of the woven type, from 250 to 300 ft. long by 140 ft. wide, made in a similar manner to those of 1882 at Delta Point. The upper end before sinking was fastened to the mooring barge by ten 1-in. lines. Two 1½-in. or 2-in. lines were attached to the mattress by means of pin and shackle, and led to deadmen or trees on shore, both passing under the mooring barge. In sinking, the mattress was first ballasted by placing running plank on it and having the laborers carry and distribute rock evenly over it, thus destroying its flotation. When the weight commenced to strain the small lines fastening it to the mooring barge, they were slackened slowly and the mattress allowed to sink until the upper end rested on the bottom. Then a barge loaded with rock was pulled over the mat, being directed by lines from the mooring barge and bank, and the rock was thrown out, sinking the mat. At Delta Point, the fastenings between the mooring barge and mat were cut, the latter sinking rapidly.

The revetment above the low-water line was the same as at Delta Point. Some trouble was experienced from floating drift which accumulated in front of the mooring barge and under the head of the floating mattress, making it difficult to sink the latter. Many expedients were tried to prevent the destruction or loss of work through the pressure of this drift. Diagonal booms and chains were used, but without a great amount of success.

At Lake Providence Reach during the season of 1882 and 1883, the following modifications were made in the bank protection work. In the woven mats alongside of every weaving pole or every alternate one, depending on the strength required, iron rods with welded eyes at each end were placed as the mat was built, the ends of the rods being connected by lap rings or clevises. These rods added longitudinal strength to the mattress, which was much needed in strong currents

and deep water. In addition to these iron rods, at certain localities where great strength was essential, twisted wire cables were placed on the mattress longitudinally, secured at intervals to the weaving poles by short wires. These mattresses were loaded at first next the shore, and then the head was heavily weighted so it would go to the bottom quickly.

The cost of grading varied from $3\frac{1}{3}$ to $2\frac{2}{3}$ cents per cubic yard, but the material excavated was sand, which was moved with great facility.

The engineer in charge estimated, after making daily observations for over a month, that to excavate 1 cu. yd. of earth took a fraction less than 1 cu. yd. of water under a pressure of 140 lbs, with a steam pressure of 80 lbs. and a vacuum of $26\frac{1}{2}$ ins. With a steam pressure of 80 lbs. it took 3 lbs. of coal per cubic yard of water thrown or earth excavated. He also estimated shovel grading at 30 cents per cubic yard, or ten times the cost of the hydraulic work. No change was made in the upper bankwork.

The cost of the protection work at Lake Providence Reach during 1882–1883 was $11 20 per lineal foot.

At Pilcher's Point a change was made in the manner of handling the mattress by the introduction of what was called a detachable mattress head, which was used in place of a mooring barge. Figs. 11, 12 and 13 show the head and details of construction. It was made of wood and consisted of two chords 20 ft. apart, connected by a series of cross diagonal bracing and a hog chain as shown in the drawings.

"The up-stream chord was 12 ins. wide by 30 ins. deep; the lower one 12 ins. wide by 19 ins. deep. These chords were 163 ft. long and had a camber of 6 ins., and were constructed of pine planks."

During the construction the mat was fastened to this head by lines which were sunk with it, being released by means of a lever and trips.

One mattress sunk was 152 ft. wide and 1 228 ft. long. The method of using the head was as follows: The sinking was commenced near the center, the mattress being loaded with rock both ways from this point until it had reached a depth of from 10 to 30 ft. Then two rock barges were lashed together and placed about 50 ft. from the head and allowed to drift over the partly sunken mattress, rock being thrown on the latter until it reached the bottom. Previous to the final sinking the depth of water over the outer edge of the mattress head was taken by means of a sounding line fastened to it. When the mattress had

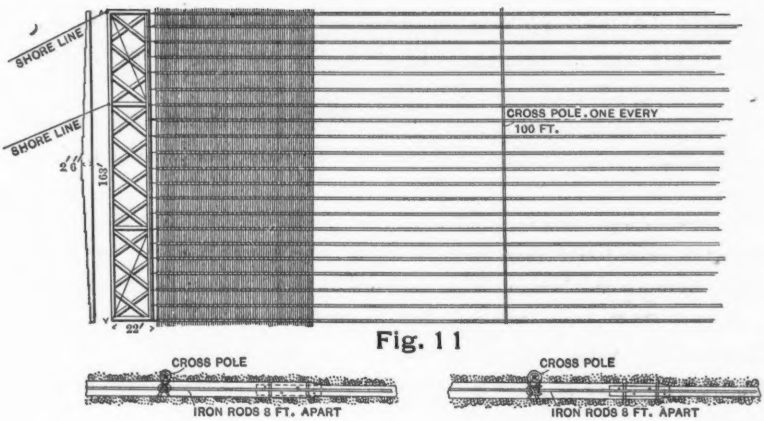


Fig. 11

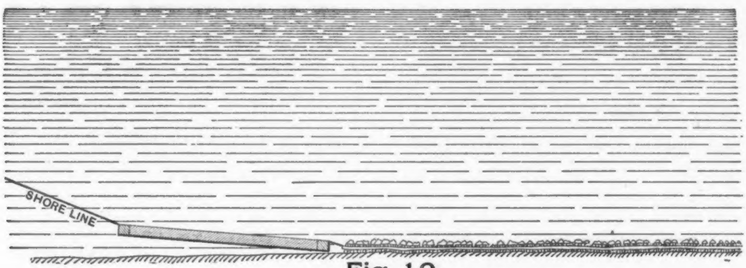


Fig. 12

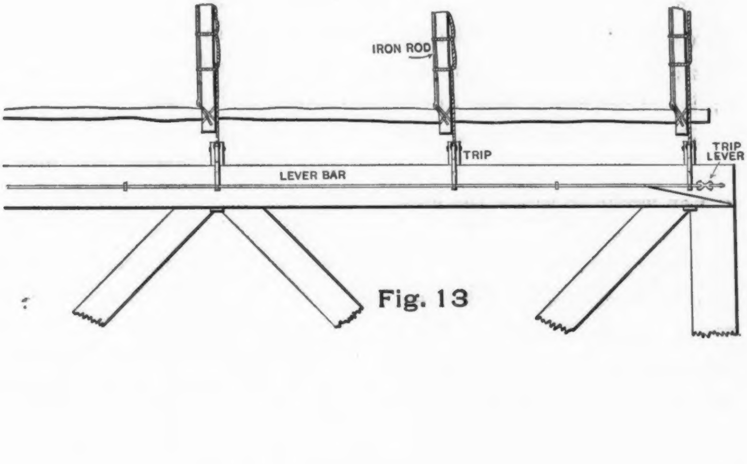


Fig. 13

sunk to two-thirds the entire depth, ten men, by pulling a line made fast to a ring at the end of a lever, tripped the triggers, releasing the head at once; the mattress sank with its load of rock to the bottom, and the head rose by means of its buoyancy to the surface. This mattress head was not generally adopted, the old method of mooring barges being adhered to, even to the present time.

The first work of revetment construction under the direction of the Mississippi River Commission at New Orleans was commenced in 1883.

Floating ways 400 ft. long were constructed by linking ten barges together, each 100 ft. long by 20 ft. wide. The woven mattress was used, the weaving poles having iron rods fastened to them. The poles and rods were 25 ft. long, the rods linked together at the ends making a continuous weaver. Two No. 8 wires were run through and across this mattress every 12 ft., and heavy binding poles also transversely every 25 ft.

After a very high stage of the river in the season of 1884, it was found that in many places in the long reaches of protected bank, the revetment both above and below the low-water line was too light to prevent the caving, and at some points the work was considerably damaged, necessitating changes in methods, strengthening and enlarging. Much unfinished work was destroyed because of lack of funds.

Work at Memphis in 1884.—One of the localities to suffer during the flood was the Memphis front. There the channel directly against the bank deepened materially, undermining the small mats sunk in former years. To prevent further damage and in order to replace the destroyed work, mattresses varying from 150 to 300 ft. in width were sunk and the upper bank graded and paved with stone.

The 300-ft. mat was constructed by placing two coal shells together end to end as a mooring barge, and two mattress barges also end to end on which to weave the mat.

In the construction of this 300-ft. mat two ⅝-in. iron rods, ten ½-in. iron rods and three ⅝-in. wire ropes were used longitudinally. It was secured to the mooring barges by 1-in. and 1¼-in. manilla lines every 16 ft. across the head. Seven shackle lines from 1½ to 2 ins. in diameter ran from the head to fastenings on the shore, and the mooring barges were held in place by nine lines 1½ to 2 ins. in diameter

leading also to the shore above. Lines were placed diagonally across the mat every 100 ft. and fastened to the shore. This was one of the first very wide mattresses constructed, and notwithstanding its additional strength and the increase in fastenings, it was broken up in sinking. The engineer in charge of this work does not report the cost of this large mattress, but estimates for upper bank revetment 100 ft. wide, $6 80 per square, and for all protection work, upper slope 3 to 1, bank work 100 ft. wide, and subaqueous work 150 ft. wide, $17 per lineal foot. During this same season on the Plum Point Reach the width of mattress was increased to 175 ft., one mattress being constructed of this width and 2 010 ft. long, another 175 x 1 750 ft., and a third 175 x 1 713 ft. Five wire cables were used in the body of these mats longitudinally.

The grading for shore protection was done with hydraulic power at 2 cents per cubic yard.

The distribution of material was as shown in Appendix A.

There were minor differences made in form and mode of construction of the revetment at certain localities, to conform to special conditions and emergencies, which will not be mentioned.

The more important changes made in the old method of construction at Hopefield Bend opposite Memphis, in 1884, were the increase of mattress width to 150 ft. and the driving of a line of piles 8 ft. apart at about 5 ft. below low water, against which the shore edge of the mattress rested before it sank, not allowing it to slide up the bank on a rising water.

The mattresses were made stronger and thicker by weaving brush around but two poles, and then laying the tails over instead of weaving to the end, as shown in Plate III, Fig. 2. This allowed of much closer weaving, the tails being secured by binding poles wired down to the weavers, to which also transverse poles 8 ft. apart were fastened. Five $\frac{1}{2}$-in. iron rods and two $\frac{5}{8}$-in. wire ropes were run through the mattress longitudinally, and every 40 ft. transverse wire ropes or $\frac{1}{2}$-in. iron rods were used, fastened to the piles at the shore end. On the upper bank work wire rope was also introduced and much more stone ballast was used. The shore or upper bank revetment was extended outside of the line of piles, lapping the mattress about 20 ft.

Spur Dams at New Orleans, 1884.—At New Orleans Harbor in 1884, a continuous mattress 400 ft. wide was broken up after sinking, and as

it proved a very difficult matter to place that type of revetment along the uneven line of wharves, some intact and some wrecked, the plan was abandoned and a new method adopted, viz., the placing of submerged spurs normal to the bank at intervals of 500 to 1 600 ft., generally at salient points. These spurs consisted of a woven mattress foundation 200 ft. wide, of the ordinary form then in use, with rods and cables to strengthen it, extending out into the stream about 350 ft. from the low-water contour, with a narrow cribwork filled with rock on the edge around three sides. When in place and ready to sink, this mattress was fastened to barges on three sides by double lowering lines 1-in. in diameter 16 ft. apart. Each lowering line passed around a timber head on the barge and led thence through the mat and up to a main rope which was carried to a capstan near the shore. All these lowering lines were fastened to the main line, which was manipulated by one man at the capstan.

The shore edge of the mattress was connected by iron rods with deadmen on the bank. Six large toggle lines were fastened to the upper end of the mattress, running thence to shore connections above. The method of sinking was similar to that before employed.

On this mattress on a line parallel with its up-stream edge and 70 ft. below it were sunk in the same manner six wooden cribs about $5\frac{2}{3}$ ft. thick, containing pockets in which rock was placed to sink them.* The bottom crib was 60 ft. wide, and the top one 22 ft. The completed cribwork was about 300 ft. long. The bottom crib was made the length required to fit the contour of the bank, the others varying in length in order to give the completed dike a top surface slope of about 3 to 1 from the low-water mark to the river-bed.

The cribs were made of sawed timber frames connected by long iron bolts and wooden posts fastened with wooden pins, between which and forming the body of the crib was placed willow brush, pockets being left in the construction in which to place the rock for sinking. In sinking the mattress about 7 lbs. of rock was used on each square foot of surface, the crib taking about 7 lbs. for each cubic foot of structure.

The mattress cost $7 60 per square, and the crib $3\frac{1}{3}$ cents per cubic foot. The total cost of one completed spur was about $12 525.

* The number of cribs in a dike varied with the depth of water, cross-section of banks, etc.

Results of Early Works.—By 1885 experience had demonstrated very forcibly the necessity of strengthening all the work of revetment or bank protection that had to withstand the continued force of the current and prevent the sloughing of the bank. Two very active forces to contend with were the seep water that undermined the slope, and the drift that accumulated at the head of the subaqueous work during construction, tearing out the fastenings by the increased pressure and doing great damage to the mat proper. The old mattresses were small and easily handled during construction, but when in place proved but a temporary protection, except at points where the material composing the bank was very hard and tenacious and the current and depth comparatively slight; whereas the new work offered great resistance to the current, especially while sinking, necessitating many more and very strong fastenings. This fact was not thoroughly appreciated until many accidents had occurred. Even during comparatively low water the drift falling into the river from caving banks gives trouble, and when a considerable rise finds a revetment party with an unfinished mattress in an exposed position, the danger from that source is very great. The drift accumulates under the mat head, forming a much greater surface of resistance to the current which has to be borne by the head lines, making the task of getting it to the bottom safely a very difficult one to perform.

At Memphis Harbor in 1885, the head of the mattress was strengthened by more and better iron chains, and by weaving through the mattress near its outer edge one 1½-in. and two 2-in. manilla lines. For a 600-ft. mat 250 ft. wide, sixteen head lines and three diagonal lines were used, nearly all being 2 ins. in diameter. At this time the engineers at all points began to advocate a greater strength of mattress and fastenings.

The methods adopted to prevent the sloughing of the upper bank and general destruction by seep water varied at different localities. When the water came through the bank in well-defined streams, tiles or drains of wood or stone were used. At one place a trench 90 ft. long by 4 ft. wide at the bottom and 16 ft. deep was dug and filled 6 ft. with rock, proving of great benefit.

The distribution of material in 1885 and 1886 is given in Appendix A.

By 1887 the general cost of finished standard bank protection was from about $25 to $30 per lineal foot, depending on the locality,

width of mattress, etc. This included all expenses of repairs and administration.

In this year on the Plum Point Reach the experiment was made of protecting the bank in a certain bend by detached pieces of revetment at intervals of about 500 ft. The results obtained and the discussion of this method will be given further on.

Work Done in 1887-88.—"Prior to 1873 the portion of the river bank at Memphis constituting the harbor front was comparatively stable. In 1876 it had receded 350 ft., and continued to cave at the rate of 100 ft. per annum." The next year, 1877, Congress directed that a survey be made and a report submitted. The plan adopted was for protection by revetting the bank with willows ballasted with rock. This work was carried on without much change in bank line up to 1884, when the new and more substantial revetment was adopted. About that year a complication of changes took place in the river in that vicinity. Hopefield Bend Point was caving away rapidly, thus throwing the resultant of greatest pressure lower on the Memphis side, relieving much of the bank already revetted and threatening the paved levee and the landings below. By 1887 the greater part of this front had been protected, but the continued recession of the Arkansas side, and the accumulated energy in the water passing along the lower revetment on the city front, augmented the caving still further down the river, where the bank conditions are very different from those existing above. Instead of a sloping paved levee from low water to high, the bluff rises nearly vertically to the height of about 100 ft. Here spur dikes somewhat similar to those used at New Orleans were substituted for the continuous revetment. The spurs were placed about 500 ft. apart between centers and reached from the foot of the bluff to the bed of the river.

These spurs were constructed partly by funds contributed by the city of Memphis and partly by Government appropriation. The mode of construction in its general features was similar to that in use at New Orleans. The foundation mattress and cribs, one placed on another, reaching the required heights and inclination, were sunk in practically the same manner. A more minute description of the method of spur construction is given under the head of "Details of Greenville Dike Construction," where the author was in local charge and the work was practically the same as that at Memphis.

In 1888 the whole system of revetment at Memphis comprised a

bank protection of willows and stone about 2 miles in length, and it was estimated that 1 mile more would be required to complete the work. In Hopefield Bend, opposite and above Memphis, it was estimated also that 1 mile farther down stream would have to be protected to hold Hopefield Point, in order to control and guide the channel of the river in the desired direction.

The distribution of material and cost of work during the season at Hopefield Bend and Memphis Harbor are shown in Appendix A. The cost of the Hopefield Bend work from September, 1887, to January, 1888, subaqueous mats and upper bank revetment combined, including administration, repairs to plant, towing, etc., was \$4 44 per square covered.

At Greenville, Miss., a similar project to that undertaken at Memphis was adopted. The dikes were constructed partly by funds contributed by the town. Ten dikes were built, nine of about the same form as those used at Memphis, and one having cribs formed with frames of 3 x 4-in. sawed gum lumber, in lengths of 8 and 16 ft., fastened by ½-in. bolts at each intersection. Here in constructing the upper-bank revetment the old method of carrying and distributing rock on the willows by hand was abandoned, and a carrier devised to take it from the barge and distribute it along the slope. It consisted of a pile-driver placed outside of the stone barge, and a wire rope 1⅛ ins. in diameter, fastened to its leads and passing thence to and over a trestle about 16 ft. high on top of the bank, anchored to a deadman or stump 40 ft. back. A box was suspended from a traveler which ran on the wire rope and was actuated by the hoisting machinery on the driver, and unloaded by a trip line manipulated from the ground.

On this work, the upper portion of the upper-bank revetment had two layers of brush instead of one as had been the custom.

The ten dikes constructed during the season cost, including towing, \$101 011 03, or about \$10 101 10 each. About 5 000 ft. of bank was thus protected, at a cost of about \$20 20 per foot.

At New Orleans Harbor the methods of dike construction were modified in order to get a more substantial form of protection. The iron rods in the cribs were dispensed with and replaced by wooden stanchions, the thickness of the cribs was increased to 6 ft., the depth of rock pockets was reduced to about one-third the thickness; the cribs were loaded as heavily with rock before being lowered to the

bottom as the lowering lines would stand, and no rock was thrown on them after being placed on the mattress. The cost of the New Orleans cribwork was 4 57 cents per cubic foot, excluding care of plant, etc. One mattress cost $7 54 a square, and another cost $9 11. The rock for this work cost $4 11 per cubic yard.

Work Done in 1888-90.—Up to the year 1888 the purpose for which bank revetment had been used was, as has been demonstrated, the protection of valuable property, wharves, landings, warehouses, etc., and maintaining the river in certain reaches within given limits of curvature and position with reference to shoals and bends above and below, in order to regulate low-water depths, etc.

In 1888 it became apparent that unless some action was taken to prevent the caving in some of the lower bends, cut-offs would occur, producing very radical changes in the regimen of the river for many miles above and below. To prevent this occurring at Ashbrook Neck, the upper bend of the peninsula was revetted with the standard type of continuous mattress and upper-bank work. Also at Lake Bolivar, where the bank was receding gradually toward the large inland lake, and the river threatening to turn a portion of its water into the back country, the formation of the outlet was prevented by the use of continuous mattress protection.

This year the mattress work at Plum Point Reach was 200 ft. wide, and was held out to near the low-water line by piling; the upper bank was graded to a more gentle slope. On a portion of the work the brush was not placed on the upper bank, and in its place from about the 13-ft. stage, where the connecting mat ended, to near the top of the slope, stone paving was laid on the bare ground to a thickness of 10 ins. No cost is given of this first paving.

At Hopefield Bend Point and Memphis, the river continued to creep to the west and south, destroying the former point and training the thalweg toward the bluffs. It had been the purpose of the engineer in charge to allow this action to continue until the channel was in the required direction, then to check the caving on the Arkansas side with strong continuous revetment, which, when accomplished, would maintain the best depths and velocity of water along the Memphis city landing. When the time came for putting a stop to the caving at Hopefield Point, funds were not available, and the project could not be fulfilled. The point caved nearly half a mile too far before means

were obtained to check it. By that time a bar had formed at the upper end of Memphis Harbor which threatened to obliterate completely a large portion of the city landing. It is justly claimed that this filling in the upper end of the harbor is not due to imperfect methods or appliances nor to faulty engineering projects, but simply to not having the money to carry out the plans as formulated.

In 1888, 4 105 ft. of continuous standard revetment was placed in Hopefield Bend, a total width of 335 ft., the subaqueous mat being 196 ft. wide, the grade of the upper bank 3 to 1, and the upper-bank revetment 139 ft. wide.

The entire revetment, including mat and bank work, administration, care of plant, repairs, towing, etc., embracing an area 4 650 ft. long by 338.6 ft. wide, covering 15 749 squares, cost $4 75 per square.

At Bolivar Landing in 1888 the mattresses and upper-bank revetments were similar to those used at other points. The former varied in length from 224 ft. to 1 100 ft., and in width from 180 ft. to 250 ft. The cost was $91 341 78, or $6 95 per square, and $21 24 per lineal foot. Including all charges against this work the cost was $9 26 per square, or $28 31 per lineal foot. This latter would be reduced somewhat by allowing for rock unloaded on the bank, but not used, and the towing charges against it.

At Greenville Harbor the dikes, as before stated, were 500 ft. apart, leaving between them an unprotected space of about 300 ft. The foundation mats were about 200 ft. wide, extending out into the river from 375 to 415 ft. At first the dikes caused the deep water to move out toward the center of the river, the depth being increased in the channel. The 30-ft. contour moved out 225 ft. and some deposit showed on the cribs. At the upper end of the system considerable caving had taken place. To check it 706 ft. of continuous revetment was placed 250 ft. wide; also for 700 ft. below the mattress-work the bank was graded, and 250 ft. of it covered with brush. In the interval between some of the dikes sloughing had occurred which had to be repaired by mattress work.

Owing to the tenacity of the soil and the strong work placed at Delta Point, Vicksburg—about 10 000 lin. ft. in 1882-1883—but little repair had been necessary up to 1889, when a small portion of the upper bank was graded back and a revetment placed on it, with diagonal layers of brush, well covered with rock.

At New Orleans the old work placed prior to 1884 was practically intact in 1889. After 1884 the spurs had moved the deep water away from the bank 100 ft., with no increase of maximum depth, as at Greenville. The depth of water at one point where it was proposed to continue the construction of the system of dikes was found to be 150 ft. In order to make the spur conform to this depth and have the required surface elevation, it was necessary to build the cribs 450 ft. long and the mattress longer. The ways not being of sufficient length, a supplementary mat was constructed and placed at the outer edge of the woven mattress, being over 100 ft. wide. This supplementary mattress was made on the plan of those used in the sill dams at the head of the Atchafalaya, mouth of the Red River, and somewhat similar to the old pin and frame construction described in the beginning of this paper. It was made of 2 x 4-in. scantling frames, placed 8 ft. apart. Top and bottom frames, with brush between, were joined together by 2-ft. stanchions, fastened in sill and cap by a 6-in. wire nail and a ¾-in. pine treenail. The willows on the bottom layer were nailed to the frame to strengthen the mat and keep it from pulling apart. This mattress was sunk 300 ft. from the shore in about 153 ft. of water and in a current of about 5 ft. per second. An additional lowering barge had to be placed outside of those used for the main mat; guide chains from anchors formed of loaded kegs were used also to insure accurate sinking. The mat was loaded and sunk in the customary manner. It cost $9 56 per square; the woven mat, $6 39 per square. The cribwork placed on these mattresses cost 4 cents per cubic foot. This dike when finished was the largest submerged spur ever constructed on the Mississippi River, and probably in this country.

In the autumn of 1889 the work of protecting the bank at Hickman Harbor, Ky., began. Hydraulic grading and the usual method of bank revetment were used. The first mattress was sunk on a projecting point, necessitating the use of anchors in order to get a correct lead for the head lines. The Chinese anchors used, the positions of the barges, etc., are shown in Figs. 14, 15, 16 and 17. The mattresses were 300 ft. wide by 750 ft. long, connected by shore mattresses to the upper-bank revetment. The cost of the work complete was $24 77 per lineal foot.

At Plum Point in this same season all the connecting mats were dispensed with at some points, the mat being held well into the bank,

and a shore revetment constructed connecting with it before it was sunk.

At Columbus Harbor, Ky., this season, crib dikes were constructed, consisting of the ordinary woven mattress carpet, and a single crib, 28 ft. by 8 ft., extending from the upper edge of the mattress to a point 240 ft. beyond the low-water line. The longitudinal axis of the crib was about 12 ft. above that of the mattress.

The cost of the work was 4 cents per cubic foot, $6 70 per square, and $22 65 per lineal foot.

During the season the improvement of Helena Harbor was also undertaken. The project contemplated the placing of 600 ft. of continuous

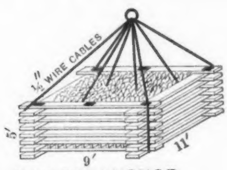


FIG. 14. CHINESE ANCHOR

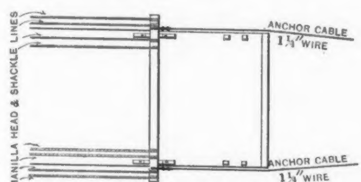


FIG. 15. PLAN OF ANCHOR BARGE AT "L"
FIG. 16.

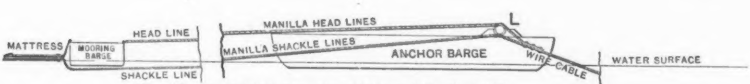


FIG. 16. ELEVATION OF MOORING PLANT

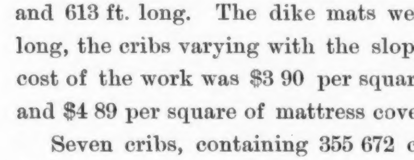
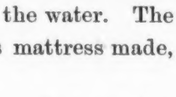


FIG. 17.



revetment and five spur dikes. The mattress work was 228 ft. wide and 613 ft. long. The dike mats were about 200 ft. wide and 330 ft. long, the cribs varying with the slope and depth of the water. The cost of the work was $3 90 per square of subaqueous mattress made, and $4 89 per square of mattress covered.

Seven cribs, containing 355 672 cu. ft., cost 4.4 cents per cubic foot.

In 1889 steel cables were used for the first time, with shackles or toggles as head lines, in place of manilla ropes. Their use had been advocated, but the difficulty of handling them caused engineers to doubt their value from an economical standpoint. Their great superiority over

the manilla line was not so much in their strength as in their durability and the fact that, as compared with manilla, they practically remained of uniform length under the strains produced in mattress sinking. The manilla ropes required a constant taking up and adjusting in order to maintain an equal pressure, whereas the steel cables could be placed at once, and the strains readily distributed throughout the system of head lines, necessitating but little change or further work. This introduction of steel cables as head lines was a very important improvement in mattress construction, reducing to a minimum the chances of loss where a sufficient number of strong shore fastenings were used. A new manilla line when subjected to great strain will stretch far beyond the limit of one that has obtained a permanent set by continued use, and when used among older head lines it produces a lack of unison in the system which is often followed by disaster.

At first the mooring barge cables were fastened to wooden cavels, but it soon became apparent that these would not have sufficient strength, so they were made of cast iron. The shore fastenings were generally deadmen, with keys or timbers 18 to 24 ins. in diameter. At this time it also became apparent that much of the loss by sloughing down of the bank was due to the fact that it was not graded to a light enough slope. Of course, in many places to overcome entirely the tendency to slough, it would be necessary to grade to an exceedingly gentle slope, the angle of repose of wet earth, but this was not advocated, it being deemed advisable to grade to about 4 or 5 to 1 only, thus reducing to a practical minimum the sloughing tendency. The additional cost of flattening the slope was compensated for by leaving from 8 to 10 ft. at the top of the bank vertical, or with its natural inclination prior to grading. It was found that little or no caving took place at the crest when the rest of the bank was protected.

It was suggested that planting Bermuda grass on this upper slope would be advantageous, but this was found to be a poor expedient as a protracted high-water season would kill it. Willow plantations have been more successful, but they add very little strength and cause but slight deposit in the rapid current along the protected bank.

On the Lake Providence Reach, Louisiana Bend, the upper bank was first graded to a slope of about 4 to 1 and then paved with rock to a thickness of 10 ins. The rock was carefully laid by hand directly on

the bank, no willow revetment being placed under it as a foundation, as had been formerly the custom.

Where the upper bank had been previously revetted with willow brush ballasted with stone it was found that in about four years the willows above the low-water line rotted out, necessitating an entire renewal, which meant the removal of the work and redressing of the bank. It was expected that by placing the rock directly on the bank this would be avoided, and by making it thick enough it would prevent abrasion. Where the willow revetment is constantly under water it does not deteriorate except from the mechanical action of running water; whereas, if it be exposed to the air and sun it disintegrates in from three to four years. By thus dispensing with the upper-bank willow work, the first cost of revetment was considerably increased, but it was hoped that its greater permanency would more than compensate for the extra expense incurred.

The mattresses on this work were from 300 to 342 ft. wide and sunk in lengths of from about 500 to 1 000 ft.; they were built and sunk as on the upper river, against a line of piling.

Shore mattresses lapping the main mattress were used when necessary. The main mattresses were strengthened by weaving $\frac{7}{8}$-in. wire cable longitudinally through them, spaced 16 ft. apart, and placing holding-in cables, every 16 ft. across them. The latter were fastened to deadmen on the shore, and tightened by tackle blocks after the upper slope was graded.

The grading here was done after the subaqueous mattress was sunk. The engineer in local charge, Arthur Hider, M. Am. Soc. C. E., claimed this to be bad practice, giving among others the three following reasons for grading the bank before building and sinking the mattresses.

First.—The graded bank allowed the holding-in cables to be placed permanently, with the proper strain and position to insure the mattress sinking in the desired place.

Second.—By dispensing with the piling the mattress would sink on a uniform slope, not being canted up on steep uneven ground.

Third.—The rock could be unloaded directly on the finished slope, not necessitating double handling.

The labor cost of the work was \$71 679 16 for 27 367 squares, or \$2 62 per square.

At Greenville in 1890 the spur dikes were intact, but the current

was attacking the bank at the upper end of the system, threatening its destruction. The dikes could not be considered entirely successful. At some points the bank in the unprotected intervals between the cribs had caved badly. At some the 30-ft. contour had moved out, but at others the reverse was the case, while in much of the improved reach the outer ends of the dikes had been undermined. The amount of deposit between the dikes varied at different seasons, with the change in the stage of the water and its height.

In 1889 the author added two dikes at the head of the Greenville system, and as they were built in a practically similar manner to those sunk in previous years and those adopted for other harbors, a description of the details of construction will cover all the partly submerged spur types in use on the river.

Details of Greenville Dike Construction.—The dikes consist of cribs made of willow poles and brush fastened by wire and spikes, having pockets formed in them in which rock is placed to sink them, and having for a foundation a mattress woven and sunk in the manner heretofore described. They are placed normal to the bank line and 500 ft. apart, and reach out beyond the deepest water in the channel next the shore. The purpose they are expected to serve is the protection of the bank immediately at the point they occupy and the indirect protection of the intermediate spaces by deposit, due to the eddy and dead water, formed by their position relative to the swift current of the river.

After an accurate hydrographical survey of the locality to be improved, a mattress 290 ft. long by 290 ft. wide extending about 50 ft. beyond the deepest water was constructed on floating ways, of willow brush and poles, wire and spikes, and launched into the river as woven. After being fastened by cable shackle lines to the shore above, it was ballasted and then sunk in the usual manner.

The mattress was the foundation for the main body of the dike, which was formed of cribs. The dimensions and general form of cribs were governed by the profile of the bank immediately at the point where the dike is located. The dike under consideration contained but two cribs, the lower one 212 ft. long by 32 ft. wide and 8 ft. deep, of uniform section; the upper one, 170 ft. long, 16 ft. wide and 8 ft. deep. The longitudinal axis of the cribs was 90 ft. below the up-stream edge of the mattress. The dike was finished with as nearly a uniform surface as possible, having a slope of 4 to 1 from the river end to the top of

the graded bank. The cribs were each right rectangular prisms in general form. Where four or five were required, the top one was 16 x 8 ft., the next 32 x 8 ft., the next 48 x 8 ft., and so on, the last one sometimes being constructed to conform to the irregularities of the bottom, but having a uniform top surface.

The details of crib construction were as follows:

A framework of poles and willows was laid on the floating ways on which the mattress was constructed, in 8-ft. squares, to the required length and breadth. On this frame layers of brush, both longitudinal and transverse, were placed, and on these another frame similar to the first, then other layers of willows followed by a frame, and so on until the crib had attained a thickness of 3 ft. Then the frames and intermediate layers of brush were thoroughly sewed together with No. 12 wire and 9-in. spikes, wire being left projecting far above the last frame to fasten the lower to the upper cribwork. When the construction had reached this stage the partly finished crib was launched from the mat barge and placed over the mattress on which it was to rest. It was then fastened by lines to the mooring barges, which held it in place, and also connected with the shore by shackle lines leading well up the river.

At the intersections of the frame poles, 8 ft. apart, upright posts 9 ft. high were then securely fastened, and to these, as well as to the lower frame, the crib was built, pockets or compartments being formed in each 8-ft. square, the shape of an inverted frustum of a pyramid, by dropping back one pole as each layer of brush was laid above the bottom 3-ft. foundation. When finished the crib was 8 ft. deep, with pockets 8 ft. center to center, about 5 ft. deep, and each capable of holding about 3 cu. yds. of loose rock. The whole crib was securely held together throughout with spikes, wire and $\frac{3}{8}$-in. cables. The process of sinking was practically the same as in the case of the mattress. After the crib was securely fastened to the bank by cables placed carefully over the mat in the desired position, and after being checked up well by slip lines to the mooring barges, rock was thrown into the pockets until they were filled. When the weight had considerably more than overcome the buoyancy of the structure, the strain on the lines being very great, and the crib in a sinking condition, then the slip lines were rendered slowly, care being taken to keep the strain uniform until the crib settled in its place on the mattress. In the case

of the second crib, it was built 16 ft. narrower, as before stated, and sunk in the same manner on top of the first one, thus forming a sill 16 ft. high.

After the mattress was constructed and sunk, before the cribs were started, the portion of the bank above the mat and water line was graded to a slope of 4 to 1, preparatory to covering it with a revetment of willow and stone, which was connected with the submerged mattress.

The grading was done with a sluice as before described.

After completing the grading, the revetment was laid; first a framework of poles in 8-ft. squares, then two diagonal layers of brush placed on it, then another framework corresponding to that below, and the entire mass tied together securely with wire and spikes. On this, stone was laid close enough to hide the brush.

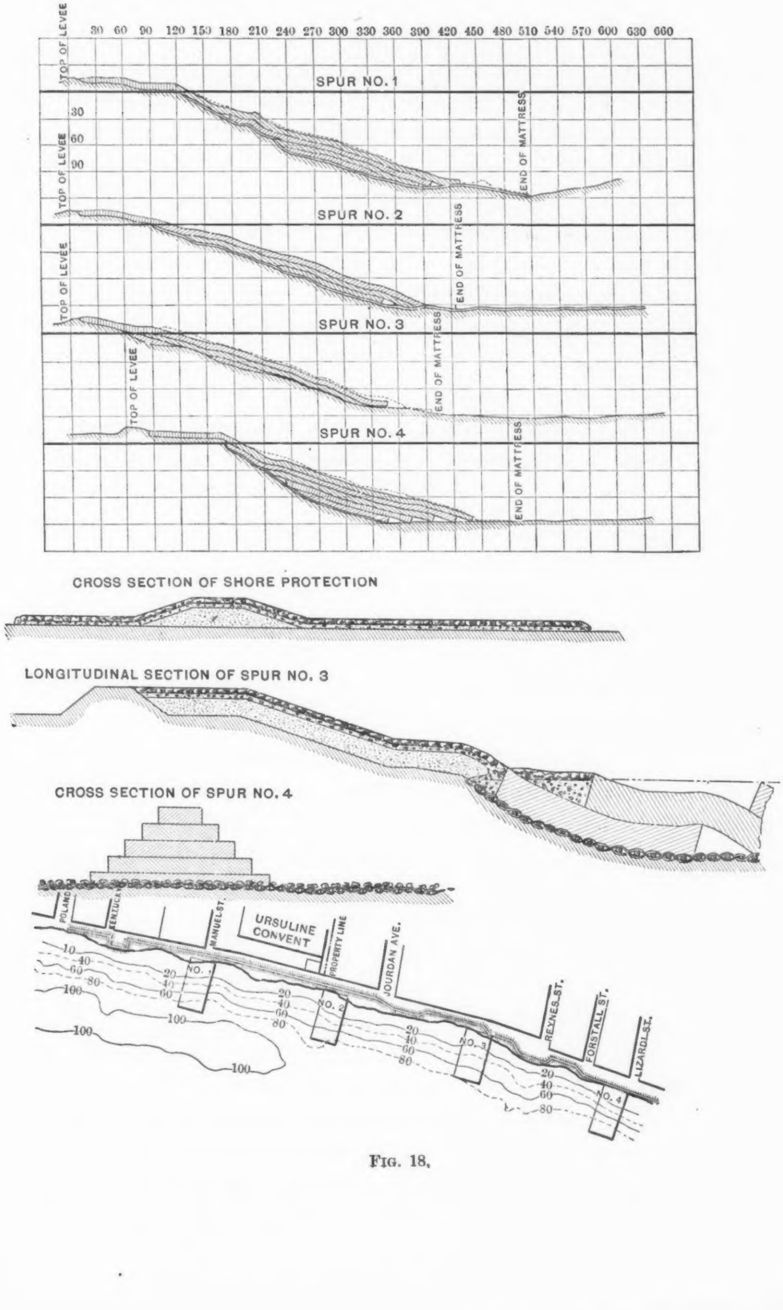
When the revetment was finished and the mattress and submerged cribs sunk, the upper end of the latter was joined to an upper-bank crib which carried the regular slope of the top surface of the dike to its intersection with the upper bank.

This upper-bank crib, though constructed on the ground, was in form similar to those made on the ways, and formed but the continuation of the subaqueous work.

The brush for the work cost per cord....	\$1 27½	and	\$1 09
The poles, per cord....................	1 47½	"	1 48
The rock, per cubic yard........	1 50	"	1 95

All of the material was delivered, the brush and poles at the contractor's camp, and the stone at the work on board of government barges, for that price. The total money expended in building two dikes was \$24 037 76. More cables and other materials were used in these dikes than had formerly been the custom. The field cost and material used in their construction is shown in Appendix A.

The total cost of the dike was: Foot mat, \$3 830 49; crib No. 1, \$1 698 73; crib No. 2, \$871 55; revetment, \$3 167 82; shore crib, \$92 69; total field cost, \$9 661 28. The gross cost of the entire work was considerably greater than the net cost as shown in this dike would indicate, because of the difficulty of obtaining good labor during that season, the run of drift, the remoteness from the base of supplies, and the excessive amount of material used in the first dike constructed, the cost per unit being much in excess of that of the second dike.



30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660
TOP OF LEVEE
SPUR NO. 1
30
60
90
END OF MATTRESS
TOP OF LEVEE
SPUR NO. 2
END OF MATTRESS
TOP OF LEVEE
SPUR NO. 3
END OF MATTRESS
TOP OF LEVEE
SPUR NO. 4
END OF MATTRESS
CROSS SECTION OF SHORE PROTECTION
LONGITUDINAL SECTION OF SPUR NO. 3
CROSS SECTION OF SPUR NO. 4
POLAND
KENTUCKY
MANUEL ST.
URSULINE CONVENT
PROPERTY LINE
JOURDAN AVE.
REYNES ST.
FORSTALL ST.
LIZARDI ST.
NO. 1
NO. 2
NO. 3
NO. 4

FIG. 18.

The cost of continuous repair revetment work at Bolivar Landing during the season of 1889 was $10 68 per square.

New Orleans Spur Dikes.—In 1890 the construction of spur dikes at New Orleans was continued. There the dikes were much larger than at other points. In that portion of the river, this particular kind of bank protection is especially well adapted to the existing conditions. As before stated, the small variation in elevation of water surface, as compared with points above Red River, the less rapid caving and the more uniform flow, all produce a condition favorable for the adoption of that method.

One of the dikes built this season was the largest ever placed in the river. It contained about 3 400 cords of willows, 80 000 ft. of lumber, 2 000 tons of rock, 5 500 lbs. of wire, 60 kegs of nails and spikes, and 8 000 lbs. of iron rods and chain. Its length was 430 ft., and height 60 ft. The depth of the water at its outer edge was 152 ft.

The dikes were constructed of sawed lumber frames in place of rough willow pole frames, as in the upper-river work, and they were formed of cribs in some cases five and six tiers high. Fig. 18 shows cross-section of some of these spurs of 1890.

This season a departure was made from the plan before adopted, which changed the dikes from purely submerged structures to a form somewhat similar to those used at Memphis and Greenville. This consisted in carrying the dike above low water by connecting it with an earthen levee with a crown of 10 ft. and slopes of 3 to 1, the bank being first graded to a gentle slope. On this levee rock was placed to a thickness of 9 ins., forming a pavement covering the levee and extending 20 ft. above and 50 ft. below it (see Fig. 18).

The average field cost of these dikes in 1890, not including administration, repairs, etc., was $7 15 per square for mattress work and 3.6 cents per cubic foot for cribwork. These spurs average 1 000 ft. apart.

The standard revetment by this time had become generally adopted, and consisted of continuous revetment and dike construction. The standard revetment as used in 1890 in the upper districts is described in detail in the report for 1891 of the Chief of Engineers of the United States Army. As the woven mattress and willow upper-bank revetment had reached its most perfect form, and was shortly to be replaced by an entirely different kind of willow work for the subaqueous portion and paving of the upper bank, a description of it will

be given as illustrating the highest development from the crude methods of 1882 of this type of protection work.*

Construction of Standard Bank Protection, 1890.—After staking out the top of the slope to a grade of 4 to 1, measuring from the low-water line, the bank is cleared of all trees and trash 50 ft. back of the top.

When the clearing has been carried ahead a sufficient distance, one or two hydraulic graders are started and the bank sloped in the manner heretofore described. "After grading, the bank is dressed by hand, all holes being filled up with brush and dirt."

Either after or before grading, the latter being preferable, all snags are removed from the bank in the reach in which the mattresses are to be placed. Two methods are resorted to, blasting and pulling with steamboats. The snag boat method is less expensive, but more satisfactory if followed by the submarine diver.

When a considerable reach of bank has been cleared, the snags removed, and the grading completed, an abutment is constructed consisting of two piles driven 15 ft. apart and parallel with the bank, and 10 to 15 ft. inside the low-water line. Out from and directly opposite these, at the low-water line are driven two clusters, with two piles in each cluster (see Fig. 19). An inclined brace connects each cluster to the pile behind it. These piles are left about 10 ft. above medium low water. The braces are sawed off flush with the outer face of the twin piling, to allow for mooring barges.

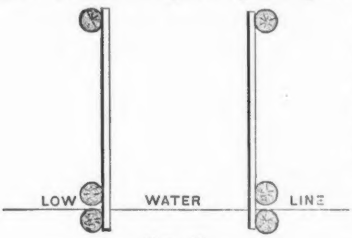


Fig. 19.

On this abutment, when the mattress barges are swung into place, the inside edge of the mooring barges rest, and are held out to the required position. Below this abutment, on the zero line, single piles are driven 100 ft. apart for the full length of the required mattress, the top of these piles being left, as in the case of the abutment clusters, about 10 ft. above the medium low water. By means of this piling the mattress is kept over the zero line during a limited fluctuation of the water surface, while being constructed and sunk. After the mattress is on the bottom, all these piles are cut off or pulled out, as they would otherwise form obstructions to navigation.

* See the paper by Mr. A. G. Nolty, assistant engineer, on details of construction of bank protection works, as practiced at Plum Point Reach in 1890. "Report of the Mississippi River Commission," 1891, p. 3606.

"While the abutment is being constructed two mooring barges lashed end to end are placed alongside of the bank above the abutment. Outside of these barges, parallel with them and with the ways touching the gunwale, is placed the mattress or weaving barge." The head lines connecting the mooring barges with deadmen or trees on the bank consist of six wire rope cables, the up-stream one $1\frac{1}{4}$ ins. in diameter, the next two $1\frac{1}{8}$ ins. in diameter, and the last three 1 in. in diameter, as shown in Fig. 20. These cables have an eye spliced in one end, which is used for fastening them to the cavel of the mooring barge. On the up-stream edge of the latter the timber heads have heavy iron bands forming eyes through which the eye of the cable is brought and fastened by a $1\frac{1}{4}$-in. iron bolt.

While the mooring lines are being run, the head of the mattress is under construction.

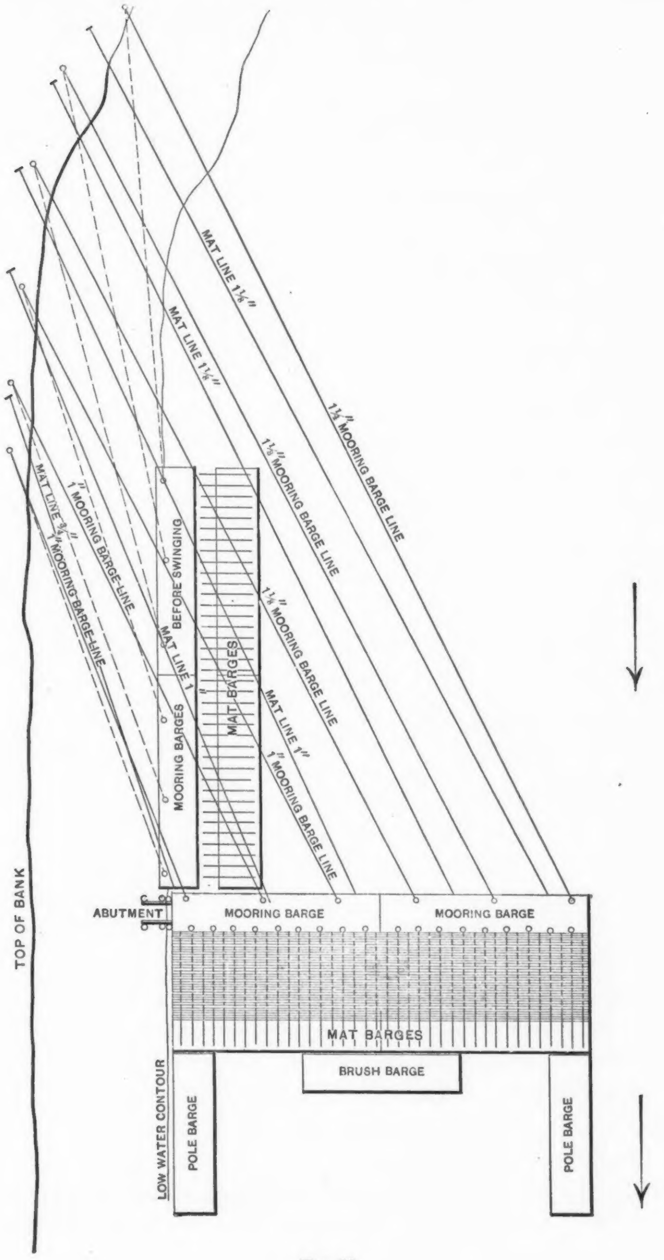
"Hardwood poles, as large as can be conveniently handled by a gang of men and reasonably straight, are laid in two lines on the ways over and parallel to the inner gunwale. These poles lap each other 10 to 15 ft., the two lines breaking joints. Where they lap they are spiked together with $8\frac{1}{4}$-in. spikes every 2 ft., and also tied together with No. 12 galvanized wire at intervals of 10 ft., except at the laps, where two ties are made. This line of poles is equal in length to the width of the mattress."

Upon these poles, at intervals of about $7\frac{1}{2}$ ft. and at right angles to them, the butt ends of the weaving poles are securely fastened with two 8 x $\frac{1}{4}$-in. spikes and a lashing of No. 12 wire. Upon these latter another set of poles similar and parallel to the first are placed, spiked and wired, and the whole head thus formed securely fastened with wire.

"The weaving poles are live willow or cottonwood brush reasonably straight, and 4 to 6 ins. in diameter at the butt, and from 25 to 30 ft. long.

"To facilitate weaving all knots are trimmed off and the top and bottom quickly smoothed with a draw knife. A cable made of eight strands of No. 12 wire is fastened around the head of the mat at every third weaving pole and run up alongside of it, being fastened thereto by two staples. These cables are 24 ft. long, with an eye in one end, to which, after each shift of the mat, a new length is looped in weaving. Ten continuous cables are thus formed in the mat, greatly strengthening it longitudinally."

While the head is being formed the mattress head lines are being run out, and when it is finished they are fastened to it. These lines are five in number; one near the outer edge of the mattress, $1\frac{1}{8}$ ins. in



MAT LINE 1⅛"
MAT LINE 1⅛"
1¼" MOORING BARGE LINE
1⅛" MOORING BARGE LINE
1⅛" MOORING BARGE LINE
MAT LINE 1"
1" MOORING BARGE LINE
1" MOORING BARGE LINE
MAT LINE ¾"
1" MOORING BARGE LINE
MAT LINE 1"
BEFORE SWINGING
MOORING BARGES
MAT BARGES
ABUTMENT
MOORING BARGE
MOORING BARGE
MAT BARGES
BRUSH BARGE
POLE BARGE
POLE BARGE
LOW WATER CONTOUR
TOP OF BANK

FIG. 20.

diameter; then, at equal intervals to the inner edge, one, 1⅛ ins.; two, 1 in.; and one ¾ in. They lead from shore fastenings, as in the case of the mooring lines, and pass under the mooring barges, being fastened to the mat-head loop by a pin shackle. The mat-head loop is made of 2-in. manilla rope fastened to the head and running back into the mat at least 25 ft.*

"The brush used for weaving is live straight willow of any length above 25 ft., and from 2 to 4 ins. at butt.

"A full complement of men for a 200-ft. wide mat is 54, under a foreman, divided into three equal gangs, each under a master laborer. Each gang consists of five men on brush barge passing brush to weaving party, twelve men in weaving party, and one man on mat mauling brush tightly into place as the weavers push it down. Each gang builds one-third the width of the mat.

"The brush barge is placed outside (below) the mattress barge about midway between the two ends, and a barge loaded with poles is hung to each of said ends.

"A coil of 2-in. rope is placed on each end of the mat barge, and the free end fastened to a timber head on the mooring barge. The skids on the ways are well slushed with axle grease or tallow, to reduce the friction in weaving and launching. In a 200-ft. wide mat, 27 weaving poles are used. In weaving they are close to the skids or ways and at the upper end rest in brackets, bolted to the upright posts on the mattress barge.

"The brush is passed from the brush barges to the weavers who work in pairs, and is woven by them into the mattress. The butts are placed over one weaving pole and 2 ft. beyond, being woven at the other end over the next pole, under the third, over the fourth, and so on, the light ends being always left on top."

A strip 5 ft. in width is woven thus, in the next 5 ft. the butt is reversed, and so on, the butts changing directions every 5 ft. When the mattress is woven to within 2 ft. of the end of the poles, giving about 22 ft. length of mattress, it is swung in position with the accompanying barges.

The entire floating plant is swung on two lines, a 2-in. manilla rope on the outside and a 1¼-in. manilla rope on the inside of the mooring barges, having one end fastened to the shore (see Fig. 20). The head lines on the barges and mattress are slackened until the barges take a position nearly normal to the shore, with their inside edge resting on the pile abutment.

* The number and strength of lines depend on the velocity of current, the stage of water and amount of drift running. In the lower districts more fastenings, as a rule, are used than as shown above.

"The slack in the mooring barge cables is now taken in from the bank and the strain equalized. They are then fastened permanently with clamps furnished for that purpose, the mattress head lines being treated in the same manner."

To prevent the mattress sliding too far when launching a finished shift, five 1¼-in. manilla lines 100 ft. long are fastened equidistant on the mat, and pass underneath it to cavels on the ways. They are slackened off in launching. Their fastenings on the mattress can be shifted to economize rope.

"The slip lines are 1¼-in. manilla rope about 125 ft. long, there being 18 to a 200-ft. mat. Each has an eye large enough to pass over a timber head. This eye is placed over one of a line of timber heads on down-stream edge of mooring barge, the free end being passed under the head of the mat and up again on its down-stream side, and then hauled taut and fastened on its timber head. The mattress head is thus hung in 18 slings. When these slip lines are all adjusted the mat is further launched until the down-stream edge is over the up-stream gunwale of the weaving barge. The office of these lines is two-fold; they hold the head of the mat up, preventing the current and drift from forcing it under, and they are used to lower it to the required depth in sinking.

"When one entire shift (about 22 ft.) is launched, a new set of weaving poles is spliced to the projecting ends of the first set, the butts of this set being spliced to the tops of the preceding one, after having been pushed into the mat about 3 ft., thus making a lap of 5 ft. Two 8 x ¼-in. spikes and two wire lashings are used to fasten each splice. This is continued as described to within 2 ft. of top of second set of poles, when another launch is made, and so on, until the full length of the mattress is obtained."

The mooring barges were swung to a position not quite normal to the shore, but as the mattress is constructed, the greater pull on the outside lines and careful adjustment of all the strains brings them into the perpendicular.

"As soon as three shifts of mat are launched, the construction of a top grillage or framework is begun, consisting of a line of poles laid over the weaving poles and parallel thereto, lapping each other, butts to tops, from 6 to 8 ft. and wired to the weaving poles every 4 ft. by lashings 2 ft. long, made of two strands of No. 10 wire; transverse poles 8 ft. apart for the first 100 ft., and thereafter 16 ft. apart are placed in similar manner and fastened to the longitudinal ones at the intersections by 2-ft. lashings, made of four strands of No. 12 wire. This grillage is for the purpose of forming cribs, to retain the stone on steep slopes, and it also strengthens the mattress. The first set of

transverse poles along the inner edge are hardwood, are only 8 ft. apart throughout the length of the mat, and are used to connect the shore mat to the river mat.

"The construction of the shore mat, which is expected to progress with the river mat, is carried on by a gang of from 30 to 40 men under a foreman and one master laborer. The space to be spanned in building the shore mat varies with the stage of water from 0 to 60 ft. In its construction a small flat boat is generally used from which to work. Hardwood poles of the size of the weaving poles are lashed to the river mattress with three No. 12 wire lashings 2 ft. long and spiked with two 8 x $\frac{1}{4}$-in. spikes. Willow or cottonwood poles are spliced to these until they reach up the slope about 40 ft. Alongside and fastened to each of the hardwood poles is a cable made of eight strands of No. 10 wire, one end of which is fastened to two of the adjacent weaving poles, and the other to the willow poles extended on the slope. Upon the transverse poles are laid longitudinally willow or cottonwood poles 8 ft. apart, beginning with the first set about 4 ft. from the edge of the mat. The latter poles are wired to the former at their intersections with lashings of No. 12 wire 2 ft. long. The longitudinal poles are carried on lines 8 ft. apart up to the top of the slope, and on their lower side, 8 ft. apart, are driven stakes $2\frac{1}{2}$ ft. above the ground, to the top of which is fastened loosely a lashing of No. 12 wire 2 ft. long, whose bight has been first passed under the pole. These stakes are used down to the pole nearest the water edge. Upon this framework is laid willow brush diagonally with the butts toward the top of the slope and breaking joints throughout, except at the top of the slope. A second layer of brush is laid upon the first in the opposite direction, butts pointing to top of slope and breaking joints, the direction of each layer making a right angle with the other. On top of these layers of brush a second pole framework, fastened in the same manner as the first, is placed and fastened down firmly by the lashings tied to the stakes. As fast as the river and shore work is finished transverse cables made of eight strands of No. 10 wire and 60 ft. long, with an eye in each end, are run across the entire width of the mat every 16 ft., carried to the top of the bank, hauled taut and fastened to trees, stumps or deadmen. They are also fastened to the mat every 16 ft. with wire lashings."

When 400 or 500 ft. of river mattress is made, longitudinal cables* are run out from the mooring barge, one $\frac{5}{8}$-in. cable close to the outer edge of the mat, another about 30 ft. inside of the first, the third $\frac{1}{2}$ in. in diameter and 37 ft. from the second, a fourth of the same

*"These cables, which are a continuation of the mattress head cables, are furnished ready made, of the following diameters, $\frac{5}{8}$, $\frac{1}{2}$ and $\frac{3}{8}$ in., each 1 200 ft. long. They come in coils, and before using are mounted on reels."

dimensions 38 ft. inside of the third, and the fifth and last, $\frac{3}{8}$ in. in diameter and 42 ft. from the fourth, or 45 ft. from the inner edge of the mattress. All are fastened to the mattress every 16 ft., perfectly taut throughout the mat and secured to its head and foot when finished.

The cables are mounted on reels, the outside or $\frac{5}{8}$-in. one being placed in position first.

"The whole cable is reeled off, but the inner end kept on the mooring barge where the reel is set up. After being run down towards and close to the weaving barge, the spare cable is coiled down and tied for further extension. Just above the coil the cable is fastened to the mat with a wire lashing and a specially designed clamp. A tackle is then fastened to the free end and the cable hauled taut by 10 men on the mooring barge. It is then fastened to the mat every 16 ft. with a clamp and lashing. The second $\frac{5}{8}$-in. cable is next run out and fastened, where the second head cable takes hold, then follow the two $\frac{1}{2}$-in. and finally the $\frac{3}{8}$-in. cable. As weaving progresses, the cables are extended until the mat is finished, when the ends are securely fastened around the foot of the mat. After the cables are run, hauled taut, and fastened to head of the mat, all additional hauling is done from lower end of the mat."

If the mattress is to be continuous and very long, when 600 ft. have been woven ballasting can begin; but when made in lengths of from 800 to 1 000 ft., the mat is generally completed before being loaded. The ballasting is accomplished by placing a loaded stone barge outside of the mat, hanging it to the mooring barge by 2-in. manilla rope and holding it close to the mattress by breast lines.

Cottonwood planks 16 ins. wide, 3 ins. thick and 24 ft. long are laid from the barge to the mat, and are continued across the mat in 18-ft. lengths 10 x 2 ins. in section. From two to four of these runs are used and from 10 to 15 men employed on each run. These men wheel out the stone in barrows and dump it along the transverse poles, loading the entire floating mat until only the poles are above water, being careful to load the 50 ft. next the bank heavier than the rest. There is one foreman and one or two master laborers to this gang. The men on each run go out and return together. When the length of the barge is ballasted across the mat, the barge is dropped one length and the planks changed to the new position. The shore work is not ballasted until the river mat is sunk, except where stone is piled on the bank, in which case the shore work, as well as part of the river mat, can be ballasted from the bank.

"As soon as the mattress is completed and ballasted, a loaded stone barge is brought up to the mooring barge; a line is run from its head to the shore capstan of the mooring barge, and another from its lower end to the outer capstan. A man is stationed at each slip line who obeys only the word of the general foreman. Stone is thrown on the head of the mattress, and as soon as the strain on the slip lines is considerable, they are carefully slacked for a short distance. The men at the in-shore capstan begin to haul the head of the stone barge gradually over the submerged mat. The lower end is also gradually hauled up, the object being to bring the stone barge squarely across the mat, stone being continually thrown over on the mat and the barge hauled over until this is accomplished. The line from the down-stream end of the barge is then quickly shifted to another capstan as the barge proceeds in shore."

In the mean time another stone barge is brought up and placed end on the one nearest the shore and securely lashed to it, thus forming a line of barges just below the mooring barges, parallel to them and floating over the head of the mat which is about 10 ft. below the surface, but kept from sinking further by the slip lines.

"In the mean time one coil of 2-in. rope has been placed on the inner end of the first and one on the outer end of the second barge, and the end of each fastened to a timber head. A long 1-in. line also runs from the inner end of the first barge ashore, where a gang of men will be ready to haul the in-shore end of the barge down stream, should the water near the shore be without current. A steam towboat now makes fast with one line to the outer end of the outside barge. A man is at each slip line. A line of men is distributed along each edge of the stone barges. The men on shore have hold of the 1-in. hauling line, the steamboat hanging from and close to the outer edge of the stone barges, and lying with the current. The general foreman is on the mooring barges, watching the slip-line men, and everything is in readiness for the final operation.

"The general foreman now gives the word to throw the stone, and as soon as the slip lines show the required strain, he orders the linesmen on the stone barges to slacken away. He then gives the word, and the slip lines are let go simultaneously. The mat settles quickly at the head, and as the stone barges are dropped down squarely over the body of the mat, the stone being rapidly thrown on to it, it also gradually settles to the bottom. When the required amount of stone is unloaded on the mattress and it is securely on the bottom, the mattress head lines are taken up by a sailor gang, by hauling on the pin lines that are loosely fastened on the mooring barges. These lines pull the pins out of the shackles and set the cables free from the mat. The mooring barges are then allowed to swing to the bank, and all cables are reeled up on their drums, being first washed and oiled."

In the case of a bank which is caving so rapidly that the grading cannot be accomplished before the mattress is built, a foot mattress is constructed joining the main mattress with the bank, the upper bank work being deferred until the main mattress is sunk.

"The abutment and main mattress are constructed as described, except that the hardwood poles along the inner edge are omitted, and only the regular top grillage is laid. After the mattress is sunk, the bank is graded and the shore work laid down to the water edge. A connection or foot mat is then made, to connect the shore work with the submerged river mattress, as follows:

"The weaving barge is brought up alongside and parallel to the bank, with its up-stream end over the head of the mat, and a mattress built like the river mattress, except that it has a lighter head and no mooring barges are used. Instead of the heavy wire cable, wire strand is run from the head up to the top of the bank and fastened there. Five $\frac{5}{8}$-inch cables are used for every 200 ft. of mattress. Two or three cables are also run from the up-stream edge of mat to shore, to prevent current from taking it down stream. The head of the mat when launched off will lap 4 or 5 ft. over the shore work. To launch a shift, the barge is sparred away from the bank. When completed and sunk, the foot mat laps over the river mat, also, 5 ft."

Plate III, Fig. 2, shows the woven mattress under construction on the ways before the top grillage or frame of poles is added; Plate IV, Fig. 1, shows the woven mattresses under construction, partly poled on top, with the bottom frame of the upper-bank revetment in the foreground, and Plate IV, Fig. 2, shows the commencement of the operation of mattress sinking.

Work During 1890–92.—At Ashbrook Neck, during the season of 1890, mattresses were made 300 ft. wide. The bank was cleared 230 x 6 000 ft., or 31.6 acres. The bank was sandy, and was graded by a hydraulic grader, and dressed with shovels to a slope varying from 3 to 1 to 5 to 1, and a height of about the two-third stage. From the shore mat to the top of the grade was paved with rock to a depth of 10 ins.

The distribution of material was as follows: Brush, 0.708 cord per square; poles, 0.136 cord per square; stone, 1.08 cu. yds. per square.

The work consisted of 3 036 lin. ft. of main mat, equal to 8 688 squares; 980 lin. ft. of shore mat, equal to 619 squares; and 2 820 x 65.3 ft. of upper-bank revetment, equal to 1 843 squares.

The cost per square was \$7 69, and per lineal ft., \$30 42.*

* This may include the expense of a small amount of abortive dike work, undertaken at the beginning of the season.

A survey in this year of New Orleans Harbor proper showed but a small change in the bank, except a slight moving out of the 100-ft. contour. There had been no fill between the dikes, but, on the contrary, a noticeable scour. In Carrollton Bend the work had not checked the caving.

The field cost and dimensions of the dikes this year were as follows:

Dimension of section.	Greatest height.	Cost.
415 x 140 ft.	45 ft.	$17 632 05
355 x 130 ft.	50 ft.	13 008 69
400 x 120 ft.	40 ft.	10 901 79

The foundation mattress for these dikes was dissimilar to those previously described. They were made in sections, afterwards joined by wires, and not of the woven type. They were framed mats, the bottom layer of willows being securely nailed to the bottom frame. Three layers of willows were laid, the bottom and top parallel to each other. The mattress was built in four sections—three, 100 x 130 ft., and one, 55 x 130 ft. The different sections were placed in position alongside of a lowering barge and fastened together with No. 10 galvanized wire, making a mattress 355 x 130 ft.

The up-stream frames were built of 3 x 6-in. lumber and strengthened at each toggle pin by three lines of iron rods, one running straight, and one on each side of the pin diagonally, across the mattress, crossing the frames, and fastened with wire to each frame. The frames were placed at right angles to the bank, and top poles were placed longitudinally about 16 ft. apart, to keep ballast from sliding off on steep slopes, and also to give greater strength.

The dimensions of one of the mats was 355 x 130 x 1.75 ft., or 461 squares. The distribution of material and cost was as shown in Appendix A.

There was but little change in crib construction. The cribs placed on the previously mentioned mat were in number and in dimensions as follows: Crib No. 1, 120 x 56 x 6 ft.; No. 2, 152 x 48 x 6 ft.; No. 3, 170 x 40 x 6 ft.; No. 4, 200 x 32 x 6 ft.; No. 5, 274 x 24 x 6 ft.; No. 6, 310 x 16 x 6 ft.

There was 232 512 cu. ft. of material in the cribs, the cost per cubic foot being 3.57 cents. The total cost of the dike was $13 008 69.

PLATE IV.
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FIG. 1.

FIG. 2.

Other spurs built at the same time having approximately the same distribution of material cost as follows: Mattress, $9 95 and $9 48 per square; cribwork, 3.58 and 4.31 cents per cubic foot. The average cost of cribwork was 3.59 cents per cubic foot, and of mattress, $9.987 per square. It will be noticed that the cost of mattress per square far exceeds that of the woven mattress in the upper districts, and is much more expensive than the woven mattress made in New Orleans Harbor in 1890.

During the high water of 1891 the Memphis dikes settled 4 ft. at outer ends on an average.

At Fletcher's Bend it was found that the interrupted revetment, heretofore referred to, was not a success. The water attacked the bank in the unprotected intervals, causing it to cave, and it was found necessary to revet them, thus making the work continuous and demonstrating the non-feasibility of interrupted revetment in that portion of the river.

In Ashport Bend in 1891 piles were driven 50 ft. apart along the zero line. Against these the inner edge of the mattress rested, being fastened to them by yokes made of $\frac{5}{8}$-in. wire strand running across the mat and connected with it every 16 ft. After sinking the mattress the piles were cut off as close to the ground as possible.

This season, in Hopefield Bend, the cost of hydraulic grading, including clearing and dressing bank was $6\frac{3}{4}$ cents per cubic yard. The distribution of material in mattress work was: Brush and poles, per square, 0.77 cord; stone, per square, 0.71 ton.

For the connecting mattress: Brush and poles, per square, 1.40 cords; stone, per square, 1.27 tons.

The upper bank was paved at a cost of $6 12 per square. The approximate cost per lineal foot of completed revetment 200 ft. wide below zero line, with bank paved to the two-thirds stage, is given by the engineer in charge of the Hopefield work as follows: Clearing and grading, $1 59; subaqueous mattress, 200 ft. wide, $7 02; connecting mattress, 60 ft. wide, $3 36; paving, $4 59; other expenses, $3 01; total cost, $19 57.

At Ashbrook Neck in 1892 the mattresses were made from 250 to 300 ft. wide, and the bank was graded to a 4 to 1 slope. Brush revetment was carried up 5 ft. above the inside edge of the mattress, and the upper bank was paved with 10 ins. of riprap to the two-thirds stage, or 32.8 ft. on the Arkansas City gauge.

The cost of clearing the bank was $71 50 per acre; grading, $1 21 per lineal foot; dressing grade, 47 cents per lineal foot. The total cost of grading was $1 68 per lineal foot. The cost of mattress per square was $4 69, and the cost of the shore mattress was $5 33. The bank revetted was 4 460 lin. ft., and the cost $30 83 per lineal foot. The average width of the work from top of slope paving to outer edge of mattress was 419 ft.

The upper-bank work took 2.89 cu. yds. of stone per square.

The cost of this work and distribution of materials was as shown in Appendix A.

At Greenville continuous mattresses were sunk 300 ft. wide, and the upper bank graded and paved to the 30-ft. stage.

Cross cables were used extending from the outer edge of the mat some distance up the graded bank, and woven into the mattress; also from eleven to fourteen longitudinal cables, each formed of 19 strands of No. 12 wire, in a mat 300 ft. wide. To hold the mat in place during construction and sinking, ten steel 1-in. wire cables with suitable shackles and 1½-in. pins were used. These cables were in 400-ft. and 800-ft. lengths, with shore ends securely fastened. The mooring barges were held in place by four or six 2-in. manilla lines. The usual slip-lines were used, and at one or two localities Chinese anchors were resorted to.

The mattress cost $4 50 per square, and the material used was: Brush, 0.70 cord per square; poles, 0.13 cord; stone, 0.64 cu. yd.

On the upper bank 3.54 cu. yds. were used per square. The cost of this work and distribution of materials were as shown in Appendix A.

The cost of this entire work during 1892, including administration, plant repairs, etc., was $29.517 per lineal foot.

At Louisiana Bend during the same season the mattresses were made 270 ft. wide. The upper-bank work was very light in places. The material used per square was as shown in Appendix A.

The total extent and cost of the work was:

	Squares.	Per square.
Channel mattress	14 294	$5.045
Pocket mattress	3 722	6.239
Upper revetment brush	2 547	7.059
Paving	2 547	8.329

The total cost of work here during the season was $140 033 78; the amount accomplished, 23 110.5 squares, at $6 06 per square. The cost per lineal foot was $26 49.

The cost of mattress and crib work in New Orleans Harbor in the season of 1891–1892, the work being similar to that of the previous season (frame mattresses in 100 x 120-ft. sections joined together) was: Mattress, $9 28 per square; crib work, 3.7 cents per cubic foot.

Later Work of Commission.—Notwithstanding the fact that the protection work had been increased in strength from the very beginning, the whole history of the work being one of continued increase in dimensions and strength, it was still found unequal to the strain put upon it at certain localities. Surveys and subaqueous measurements and observations made in 1892 and 1893 showed a deepening and deterioration at the outer edge of the river mats at nearly all points. In the report of the Commission for 1893 there is the following statement:

"There has been a deepening from scour along the outer edge of the mats. In some cases the mat has adjusted itself to the new condition, as was intended, while in others the test of its flexibility has been too great and faults have occurred. In some places also there has been settlement in the middle of the mats rather than along their edges, indicating that greater thickness or density is required in very exposed situations. Defects have also been found between the low-water mats and those built on the graded bank.

"The mattresses used in the lower Mississippi for five years past have been the heaviest and widest ever made for like purpose in the history of engineering. To build and sink them in the deepest and swiftest stream upon which such improvement has been attempted is an undertaking of extreme difficulty. It could not have been done successfully in the earlier stages of the improvement."

In view of these facts it was determined to further strengthen the mattress and to make 50 ft. of the outer edge more flexible, so that it would conform to the new scoured slope without being broken; also to give greater stability to the junction of the subaqueous work and the upper bank revetment. It was claimed that the protection work up to that time had accomplished the purpose for which it was designed, and as it had proved to be the correct method of improvement the necessity for making it permanent arose.

When a reach or bend is not protected, the water at medium high stages and on a rising river exhausts much of its force in cutting down

the bank and deepening the bed. When the bank is protected, the currents pass over the protected portion, unable to expend their energy in work other than the infinitesimally small abrasion of the willows and rock, the water thus gathering increased velocity and greater scouring force. At the outer end of the revetment, where the current generally attains the greatest velocity, this force finds material on which it can act with greater facility, thus deepening the bed immediately at the outer edge of the mattress, undermining it and causing it either to sink and adjust itself to the new condition or break.

It is probable that this will always be the case up to certain limits of depth and rate of flow when, if the mattress work is sufficiently strong, equilibrium will obtain and the work be permanent unless attacked by forces within the bank itself and not produced by the action of the river water. Increased depth and settling at the end of the subaqueous work steepens the slope and increases the tendency of the bank to slough in badly drained localities.

The foot of the mattress should always reach beyond the greatest depth of the inshore thalweg, if possible within specified limits of economical practice.

The revetment built in accordance with the new requirements of flexibility and strength cost as follows, including all expenses except office: *Ashport Bend.*—River mats, per square, $4 27; connecting mats, $8 17; pocket mats, per square, $5 90; paving, per square, $10 11; grading, per square, 3¾ cents. *Daniel's Point.*—River mattresses, per square, $5 09; connecting mattresses, per square, $7 81; paving, per cubic yard, $1 99; grading, per cubic yard, 6 cents.

The work in 1892 in New Orleans harbor consisted in placing mattresses in the spaces between the dikes where caving had occurred or was threatened. These mattresses were practically the same as those constructed and placed under cribs the year previous, and cost $8 92 per square.

First Fascine Mattress.—At Daniel's Point in this year a new type of mattress construction was attempted, and though the conditions were unfavorable, the plant inadequate, and the labor unaccustomed to the methods, the results demonstrated the great advantage to be attained in substituting the fascine for the woven mattress.

"This new form of mat was constructed of fascines or bundles of brush 12 ins. in diameter and in lengths of 50 and 100 ft., tightly com-

FIG. 1.

FIG. 2.

pressed and bound every 3 ft. These fascines were placed at right angles to the bank and formed the woof of the mattress, longitudinal wire strands forming the warp. The top and bottom cables of each pair were clamped together every 3 ft. by long cable clamps. On top of the mattress a grillage of poles was placed and tied down to the frames by galvanized wire."

No further attempt was made in the way of fascine mat construction until 1893, and no estimate is given of the cost of that form of work until that year.

In 1892 the repairs in Hopefield Bend cost as follows: River mattress, per square, \$3 65; connecting mattress, \$5 89; paving, per square, \$11 70; reballasting, per square, \$5 50; grading, per cubic yard, 4½ cents.

At Ashport Bend a mattress was made in the same year in which much more brush was used and the longitudinal cables were doubled, one running above and the other below, reversing every 25 ft., thus forming loops 25 ft. long.

The material used per unit on the Plum Point Reach during the season 1892 is given in Appendix A.

The cost of the Third District work per lineal foot was as follows:

Ashbrook Neck.....	\$29 07	woven mattress and paved bank.
Greenville Harbor..	27 08	
Louisiana Bend...	27 86	

This averages about \$28 per lineal foot. Adding for administration, survey, plant, etc., \$6 50, the total cost is \$34 50.

Fascine Mat Construction.—The last form of woven mattress, though possessing adequate strength, was not sufficiently thick and compact to prevent the water cutting the bank through the interstices or openings between the brush. It also proved too stiff or rigid to be adjusted to the irregularities of the bank, breaking when undermined, instead of taking the new slope, no matter how steep.

The fascine mattress it was expected would be devoid of both of these defects, and though it was feared the cost of construction would far exceed that of the woven type, it was found, that after the employees became educated to the new method, the additional expense was slight.

Two forms of these mattresses were constructed, one with the fascines placed normal to the bank, and the other with the fascines

parallel to it. The former were first used, but the longitudinal fascine mat was supposed to be more flexible in a transverse direction, taking more readily the irregular shape of the subaqueous slope.

The material and plant used in the construction of these mattresses is similar to that adopted for the woven type, with slight modifications shown in Plate V, Fig 1. The following description and drawings of the details of construction of this new form of mattress, taken from the report of the officer in charge of the work on the upper river in 1894 give very clearly the mode of procedure at that time, which has varied but little at all points up to the present season.*

"The plant required consisted of one set of mooring barges, one set of barges with inclined ways, and one set of fascine barges.

"The barges of each set when placed end to end had a length equal to or greater than the width of the mattress to be constructed. The mooring barges were of the same construction heretofore used with the woven type of mattress, and were moored across the current in the same way. The mattress barges were also the same as heretofore used, with the following additions: Underneath the platform was placed a number of cable drums, one under each inclined way or skid, on which was wound and from which was played out, as the construction of the mattress progressed, the steel wire strand which constituted the longitudinal strength of the mattress, and to which the fascines were attached or woven by the method to be hereafter described. The distance between the drums was 8 or 9 ft according to the particular barge used. At the highest point of each way an iron sheave was placed, over which was passed the strand from the corresponding drum. The drums were all provided with friction brakes by which a uniform tension was kept on the strands while the mat was in process of construction. The fascine barges were ordinary square-end decked barges on which were erected temporary platforms the same level as the platform of the mattress ways. These barges were put end to end and lashed parallel to and close up to the down-stream side of the mat-ways. On the side of the platform nearest the mat-ways were erected the formers in which the brush was laid, compressed and bound into fascines.

Construction of Mattresses.—"The mooring barges being properly moored in position across the current, the mattress ways, to which had been lashed the fascine barges, were brought in position on the down-stream side and secured to the mooring barges by three lines, one at the center and one at each end. The first step was to construct the mat head. This consists of a bundle of poles, 2½ to

* Report of Captain S.W. Roessler, officer in charge of first and second districts, Mississippi River Improvement, Report of Chief of Engineers, 1894, p. 2859.

3 ft. in diameter, well bound together by wire strand, so as to form a beam of great strength, of some rigidity, but having also considerable flexibility. The poles were of hardwood, 5 to 8 ins. in diameter at the butt, and laid so as to break joints with each other. The beam is as long as the mat is wide, and forms the connecting link between the mooring cables and the mattress. It was moored to the bank by steel wire cables, independent of the moorings of the mooring barges. The number of cables used depended on the width of the mat and strength of the current. Eight cables have been used for a mat 300 ft. wide. They are spaced at equal intervals, being closest together near the out-stream end, where the current is strongest, and farthest apart towards the shore, where the current is

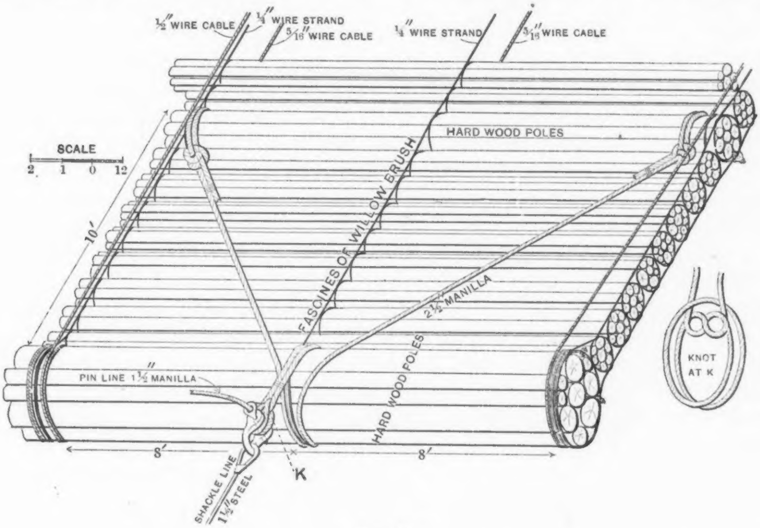

Fig. 21.

more moderate. At each point where a cable is to be attached, a heavy manilla rope, doubled, is wound around the mat head, as indicated in Fig. 21.

"Its free ends are passed over the mat and attached to a second and smaller mat head constructed in the mattress 10 ft. from the head of the mattress. The other end of the rope is connected by an ordinary shackle to one end of its mooring cable, the other end of the cable being then passed underneath the mooring barges to its anchorage on the bank. The wire strands from the drums on the mattress ways are passed over their proper sheaves and wound around and secured to the mat head. The weaving strands, which are ¼-in. steel strand and for convenience cut into lengths of about 50 ft., are also attached to the mat head, one for each of the longitudinal strands upon which the fascines are woven.

"For the construction of the fascines and the mattress the labor is divided into three gangs, one to hand the brush down from the barges, the second to carry the brush to the formers and to construct the fascines, the third to weave the fascines into the mat.

"The second party receiving the brush from the first party carries it to and distributes it in the formers. The brush is put in two layers, one with the tops in one direction and the other with the tops in the opposite direction, care being taken to break joints as far as possible, and especially to prevent two butts from overlapping. Enough brush is put in to make a fascine 10 to 12 ins. in diameter. It is then choked every 8 ft., and bound into a fascine by No. 12 steel wire. The chokers consist of iron chains of suitable length and strength, having one end secured to one side of the former. Each chain is brought over the brush and a lever inserted through a ring in the free end and borne down upon by the weight of one or two men, compressing the fascine while it is being bound with wire. The third party, assisted by the second party, raise the fascine out of the formers, slide it along the skids which connect the former with the top of the mattress ways, and down the latter to its position in the mattress next to the mat head. The weaving strand is then passed over the fascine, down underneath it and up between the fascine and mat head, crossing at the same time the bottom longitudinal strand. It is then put into a 'Haven clamp' and drawn as taut as four to six men can do it with double block and tackle. The strand is temporarily stapled to a pole of the mat head. The second fascine being in place, the weaving strand is passed over the first and second fascine, down underneath the second, and up between the first and second, at the same time crossing the bottom longitudinal strand as before. It is again attached to the clamp and drawn taut as before by block and tackle, and temporarily stapled to a piece of brush in the first fascine. When the strain is first put on the strand, a tap on the pole of the mat head to which it has been temporarily stapled is sufficient to dislodge the staple and allow the strand to completely encircle the first fascine. Details of the method of weaving are shown in Fig. 21. When the ways have been filled the mattress is launched in the usual way and the construction continued. The tenth fascine is made of hardwood brush or poles, and to it are attached the free ends of the large manilla ropes, which are wound around the mat head. The weaving and bottom strands are clamped together by a cable clamp every 10 ft., and at points intermediate between the clamps both strands are stapled to the brush, to prevent the fascines from separating in the process of weaving. On top of the mattress thus constructed are placed rows of poles 16 ft. apart, extending up and down stream. They are lashed to the fascines by No. 7 silicon bronze wire every 5 ft., and at intermediate points by strong steel wire lashings. The object of the rows of poles is two-fold;

first, they prevent the stone from slipping off the mat when it is sunk on a steep slope; and second, by being lashed to the body of the mattress by non-corrosive wire, they prevent the displacement of the brush after the steel wire, weaving strand and other corrosive connections shall have rusted away.

"At the outstream edge of the mat the poles are cribbed up two deep, to better insure against the tipping of the stone when the mat is sunk or when it is subsequently undermined by scour at its edge.

"With a mattress of this type 300 ft. wide, the maximum amount built in a day was 160 ft. with $246\frac{5}{8}$ days' labor. The ballasting and sinking of these mats is performed in a similar manner to that employed in the woven type. In ballasting it is necessary to do the work rapidly and sink the mattress immediately afterward. This precaution is made necessary by the great compactness of the brush fascines and the rapidity with which they accumulate sediment after they have been pressed under water by the ballast. So rapidly do they accumulate sediment that if there is any considerable delay in ballasting, portions of the mattress on which the ballast may be a little excessive may be carried below the surface of the water by the weight of the accumulated deposit before it is ready for sinking.

"Brush not exceeding 3 ins. in diameter at the butt makes a fascine of uniform strength, thickness and compactness.

"One-half and $\frac{5}{16}$-in. strands are used for the bottom longitudinal strands, the $\frac{1}{2}$-in. size being used at the channel edge of the mat, where the current is greatest, and the $\frac{5}{16}$-in. near the shore.

"Smaller strands than these were used in a few of the mats when the supply of the larger strands fell short, but in such cases additional longitudinal strands were stretched over the top of the mat after it was completed and clamped at intervals of 10 ft. to the weaving strand in the same manner as the latter was clamped to the bottom longitudinal cable. The $\frac{1}{4}$-in. strand is used exclusively for weaving. Two forms of clamps have been used, the 'Crosby' and a home-made clamp. Various forms of staples have been used. A staple of the fence-wire type, $1\frac{3}{4} \times \frac{5}{16}$-in., made of No. 9 wire, is a good, cheap and suitable form.

"The oblique position of the mattress head cables to the head of the mattress in the form of construction just described exerts a strong shore thrust on the mat head in the process of sinking. This thrust is taken up by the strong mat head and the mat itself, which together have the requisite rigidity to withstand the thrust without danger of doubling up.

Fascine Mattresses with Fascines Placed Parallel to the Bank.—"Owing to the very much greater lateral flexibility of the mattress in which the fascines are parallel to the bank, it was not deemed safe to have any shore thrusts at all, and the mooring arrangements were accord-

ingly modified. A set of mooring barges was anchored at the head of the mat in the usual way by mooring cables passing obliquely up-stream to deadmen on the shore. A second set of mooring barges was moored in the same way 800 ft. above the lower set. On the deck of the upper barges was placed a continuous line of log deadmen chained to the timber heads, held by the shore cables. These dead-men were to hold the cables mooring the mattress and mattress plant. As the mattress was constructed its mooring cables were attached to it in the manner to be hereafter described, passed underneath the lower mooring barges, carried up stream parallel with the bank and secured to the line of deadmen on the upper barges, thus avoiding any shore thrust upon the mat head. The mattress plant consisted of four mattress ways and their corresponding fascine barges lashed end to end, giving a combined length of 588 ft. The barges were moored parallel to the bank with the ways inclined towards the shore. The fascines were made 588 ft. long, the full length of the mattress. The mattress was constructed by beginning at the water line and extending out stream until the full width of 250 ft. was made. The details of construction were the same as those heretofore described for the mat in which the fascines are normal to the current. To give the mattress more longitudinal strength than the fascines themselves possessed, twelve ½-in. and two ⅝-in. strands, extending the whole length of the mat were built into it in the following manner: When the construction reached the desired point the longitudinal strand was stretched across the bottom strands of the mattress and clamped to them at the points of intersection by common clamps. The up-stream end of the strand was given two turns around the mattress head and carried back and clamped to itself at 130 ft. For additional security the longitudinal strands were connected together by a diagonal system of backing-up straps 100 ft. below the head of the mattress. The mattress head of this mat differed from previous construction, in that it was a kind of jointed spar, designed to adjust to the bed of the river when sunk. The spar was made of 14 cypress logs about 12 ins. in diameter and varying in length from 28 ft. next to the shore to 14 ft. on the out-stream end, all put in place before launching from mattress boats. The logs were placed on top of the mattress and about 3 ft. from the head of the mattress with laps of 2 ft.

"A ¾-in. drift bolt 2 ft. long was driven horizontally through both logs at each lap, and in addition the logs were bound together by several turns of wire strand at the pin points. The logs were secured to the fascines by two wrappings of ¼-in. strand, and to every alternate log two of the longitudinal wire strands were made fast.

"Spanning these alternate logs 2-in. manilla ropes were made fast at the same points receiving the longitudinal strands. Each of these rope loops formed an equilateral triangle, with its log for base and with

the shackles of its mattress mooring cables at the vertex. Parallel lines of poles 16 ft. apart were wired to the mattress normal to the current and bank by lashings 5 ft. apart, each alternate lashing being silicon bronze wire. The object of these poles was two-fold; first to give the mattress some stiffness, as without them it was feared the mat would be so flexible as to fold up in sinking; and second, to give to the mattress an element of permanence by its non-corrosive wire lashings. Parallel rows of poles were also placed longitudinally to keep the rock from rolling off."

During the season of 1893 at New Madrid the first large fascine mattress was made. The work consisted of a continuous mattress 250 ft. wide by 900 ft. long, an auxiliary connecting mattress, and a shore paving of 4 ins. of spalls, and 6 ins. of stone extending up the graded bank to the 27-ft. stage. The cost of this work per lineal foot was as follows: River mat fascine, $15 62; connecting mattress fascine, $2 32; paving fascine, $7 58; superintendence and care of plant, $2 26; total, $27 78.

Plate V, Fig. 2, shows a fascine mattress completed. Six mattresses of the fascine type were built and sunk, 658, 825, 913, 1 095, 1 119 and 1 125 ft. long, each being 300 ft. wide. Their cost was $6.282 per square, or $18.846 per lineal foot. Connecting fascine mats were used, costing $11 85 per square. The bank was graded to a 3 to 1 slope after the mattresses were built and sunk, at a cost of 3.8 cents per cubic yard. The shore paving was carried up the bank from the 15-ft. to the 20-ft. stage. In paving, first a layer of spalls 4 ins. thick was laid, and on this rock, 8 ins. at the water edge diminishing to 4 ins. at top. The cost was $10 11 per square, or $5 59 per lineal foot.

The average lineal feet per day's labor in building fascine mats at this point was from 0.386 to 0.495.

Recent Work.—At Hopefield Bend the repairs made in 1890, 1891, 1892 and 1893, constituted practically a renewal of all the original revetment, except two reaches, one 2 000 ft., the other 500 ft. long. These two blocks being destroyed in the flood of 1893, they were renewed by four fascine mattresses 310 ft. wide and 650, 700, 800 and 916 ft. long, costing $6.034 per square, or $18 10 per lineal foot. Connecting mats cost $6.987 per square. The grading cost 5.4 cents per cubic yard. The paving reached from the edge of the connecting mat to 26 to 30 ft. above low water, being carried to this height in order to reach above a sand stratum. The lower $3\frac{1}{2}$ ins. were composed of crushed rock, overlaid

by 6½ ins. of ordinary riprap. The cost was $9 20 per square. The total cost per lineal foot of bank protected was $31 52. For distribution of material see Appendix A.

In building the four mattresses the following averages were made in a day of eight hours.

Mattress.	Length.	Maximum feet made in one day.	Average feet made in one day.	Average number men worked per day.
No. 1	650	140	93	220
No. 2	800	135	127	280
No. 3	700	175	140	300
No. 4	916	173	153	320

At Bolivar Front the upper-bank brush revetment, having rotted in many places, was renewed by a paving of stone 10 ins. thick.

Soundings along this revetted reach showed that the inner portion of the old mattresses had silted up, but at their outer edge they had settled down from 5 to 15 ft. At the lower end of the reach during the season woven mattresses 300 ft. wide were constructed and sunk. They were nearly 2 ft. thick at the inner edge, being reduced to 1 ft. in thickness at outer edge. A much greater amount of brush was used in their construction than had before been used. For the distribution of material in them see Appendix A.

The cost was $25 08 per lineal foot, and $8 36 per square. Similar work at Delta Point cost $26.321 per lineal foot.

In New Orleans Harbor up to 1894 the following work had been done:

A continuous mat 400 ft. long placed in Carrollton Bend; five spur dikes, with intermediate revetment covering three upper intervals and about one-third the lower interval in Carrollton Bend; two spur dikes in Greenville Bend; six spur dikes in Gouldsboro Bend; eight spur dikes in Third District Reach.

In the Third District and Carrollton Bends caving took place in the intervals between the dikes. The officer in charge states:

"Spur dikes without intermediate revetment have been successful in some straight reaches, and on concave banks of large radii, but in the abrupt bends the dikes alone are only locally effective."

In the season 1893-94, woven mattresses were still being constructed and sunk in the Third District, at Ashbrook Neck, Greenville Harbor and Lake Providence. At the latter locality fascine work was also

undertaken and very satisfactory results attained. The mattresses at the other three points specified were reinforced by an extra amount of brush, at Ashbrook Neck the inner 100 ft. only having an additional layer of brush added, while at Greenville Harbor and Lake Providence Reach the extra layer was added all over the mat. The engineer in charge justly condemned the practice of obtaining additional thickness in woven mattresses by the extra layer of brush, on account of the increased stiffness attained. This was the general verdict at all other points, and the necessity for a remedy for this fault produced the fascine type. The fascine mats used at Lake Providence during this season were similar to those of the upper districts, being sunk with fascines normal to the bank.

At Lake Providence the stone on the subaqueous work was increased to 1¼ cu. yds. per square, enough to cover the mattress 4 ins. deep, and the same amount deducted from the upper-bank paving, it being deemed better practice than the old method of 10 ins. of paving and a light mat covering. The engineer recommended spalls on the upper bank in preference to larger riprap, as it packs closer, leaving fewer spaces for the water to penetrate.

The following is a statement giving the cost per unit of labor and comparative average cost per lineal foot of revetment work at Ashbrook Neck, Greenville Harbor and Lake Providence during the season 1994–95.

Cost per Unit of Labor.

Kind of work.	Ashbrook Neck	Greenville.	Lake Providence.
Mat work, woven, per square	$1.249	$1.290	$1.824
Mat work, fascine, per square	......	......	2.171
Grading, hydraulic, per 100 lin. ft	1.736	2.308	1.228
Grading, hand, per 100 lin. ft	......	3.921	0.629
Paving slope, per square	1.682	1.102	0.863

For the distribution of material on these works, see Appendix A.

Comparative Cost and Percentage of Labor and Material.

Items.	Ashbrook Neck. Per cent.	Greenville. Per cent.	Lake Providence. Per cent.
Labor	45.3	36.3	46.6
Material	54.7	63.7	53.4
Cost per lineal foot	$30 25	$28 22	$30 41

The average cost of all this work during the season was $29 33, that during the season of 1892–93 being $28, an increase of $1 33 in 1894. About 50% more of brush and 15% more of stone was used, which would more than account for the increased price.

Conclusion.—Since the season of 1894 there has been little change in the general form of bank revetment.

The vertical space is left at the top of the bank. The rest of the upper slope is paved, and the subaqueous work is of the fascine type, both continuous and auxiliary. The cost of protection per lineal foot has been approximately $30 at most troublesome localities.

Improvements, both of a mechanical and economical nature, have been attained. The fascine formers have been placed on the mattress barge, thus dispensing with intermediate barges, and mechanical devices have been designed to save labor and perform the work with greater facility and better results.

It will be noticed that in the transverse fascine mat, by dispensing with the ties which form the fascines, that is, by placing the willows in the fascine mattress, when made of the strongest form, with top as well as bottom continuous longitudinal cables, there will result a mattress somewhat similar to the old type of wire net construction used in 1880, but of much greater dimensions and infinitely stronger.

The later mattresses used in New Orleans resemble very much the old wooden pin form used at Delta Point and Memphis prior to 1880, though they are also much stronger.

The early types were more compact than the woven mattress, which was adopted in 1882 and used up to 1895, and though the latter was increased in size, and given a strength adequate to resist all strains, it was impossible to weave it sufficiently close and compact to prevent the erosive action of the water on the bank through the openings between the willows.

All the recent surveys of the revetted reaches tend to prove that where the bank is protected, no matter how strong the revetment, the channel is deepened just outside of the subaqueous work, and under its outside edge, causing it to take a steep grade. If the mattress is built with sufficient flexibility, strength and compactness, the ultimate result will be the steepening of the subaqueous slope without destroying the efficiency of the work.

When submerged spur dikes are placed in the caving bends, their

efficiency is dependent, to a great extent, on the radius of the bend, the distance between them, and the material of which the bank is composed.

Where the bend is very abrupt and the bank sandy, dikes are of little value. Where the bend is abrupt and the material clay and buckshot, they should be placed not farther apart than 500 ft., and even then it may be necessary to protect the intervals between them.

A thorough knowledge of the river in the vicinity of a reach to be protected is of great importance. Much money can be wasted by not studying the movement of its currents and bars in the locality, in order to select the best point for beginning the work. If placed too high under the bar, dead water may soon prove it a waste of material and an unnecessary expense, while at localities where the bar is receding the failure to place the upper end of the work at the correct place may prove disastrous. A careful survey of the river in the vicinity is very essential.

In the hydraulic grading and in paving the upper bank, the greatest trouble lies in the difficulty with which uniform slopes are obtained in certain materials and with strata in certain relative positions. It is often necessary to do considerable dressing and regrading with sluice boxes, shovels or teams, where the sand strata become washed in pockets some distance below the required grade.

Appendix B gives the distribution of material in the work, and the cost from 1878 to 1894.

The conditions under which the revetment was constructed, the variation in price of material and labor, the difference in form of construction and the irregular manner in which the records have been kept make any comparison of the different forms of doubtful value.

As the education of the labor to the methods has become more nearly perfect, the cost of the labor item per unit of product has decreased; but the great increase in strength, extra use of iron, etc., has partly compensated for that decrease. Since 1878 the cost of rock, brush and poles has decreased, also that of other articles used. The rate of laborer's pay per hour has remained practically the same from 1882 to the present time. The cost of subsistence has not varied to a great extent, notwithstanding the difference in cost of food supplies at different times.

The bank revetment work which the author has endeavored to de-

scribe is probably more extensive than any like engineering construction in the world. A mattress 300 ft. wide by 1 200 ft. long represents a superficial area of about 8 acres, and when one realizes that this vast willow carpet, over a foot thick, is placed on the bottom of the river in depths of from 40 to 100 ft., and against currents of from 5 to 8 ft. per second, the difficulty of the enterprise will be appreciated.

Though much of the revetment from Cairo to New Orleans has needed repairs from year to year, and in some reaches has required renewal as a whole, it may be said to have been eminently successful in the protection of harbor fronts and the prevention of cut-offs and outlets, and fairly so in the control of bank caving, and the resulting change in position and flow of the river.

At some points, where the material of the bank was friable and the currents very strong, the earlier forms of revetment proved too light and were entirely swept away, the shore line continuing to move back. Also considerable reaches of protection work needing repairs and re-inforcement at the ends have been destroyed because of the lack of funds, due to the failure of appropriations, etc. But in the later work the results have been beneficial and satisfactory, and the loss but slight.

APPENDIX A.

The following tables give the distribution of material used and the cost of revetment per unit, from 1878 to 1894. A square is equal to 100 sq. ft. Except where hardwood is designated, willow was used for brush, and willow or cottonwood for poles. Except where spalls are specified, the rock was in pieces varying from 10 to 100 lbs. in weight.

MEMPHIS HARBOR, 1878 TO 1880, MATS AND REVETMENT; 2 385 SQUARES OR 1 300 LIN. FT.

Materials.	Total amount.	Per square.	Per lineal foot.
Willow brush, cords	2 760	1.16	2.12
Cottonwood poles, number	7 520	3.15	5.80
White oak pins, 4 ft. x 1 in.	800	.33	.62
" 12 x $\frac{3}{4}$ ins.	6 300	2.64	4.85
No. 12 wire, pounds	1 950	.82	1.50
Stone, cubic yards	1 154	.48	.88
Sand bags, number	1 500	.63	1.15
Cypress piles, 40 ft. x $1\frac{1}{2}$ ins.	50	one every 26 ft.	

MEMPHIS, 1881.

This work embraced 900 squares of mattress and 131 squares of upper-bank revetment. The distribution of materials was as follows: Willow brush, 1 546 cords, 1.5 cords per square; cottonwood poles, 10 cords, 0.01 cord per square; wire, 2 430 lbs., 2.3 lbs. per square; gravel, 570 cu. yds., 0.55 cu. yd. per square; stone, 187 cu. yds., 0.18 cu. yd. per square; sacks, 1 750, 1.7 per square.

WOVEN MATTRESS WORK, DELTA POINT, 1882 AND 1883.

Items.	Amount. Per square.	Amount. Per lineal foot.	Cost. Per square.	Cost. Per lineal foot.
Brush, cords	.41	.6	$1 03	$1 52
Poles, number	1.2	1.66	38	53
No. 12 wire, pounds	1.2	1.70	06	08
Spikes, 6-in., pounds	.34	.5	02	03
Nails, pounds	.21	.3	01	01
Rock, cubic yards	.42	.6	80	1 14
Labor	....	....	60	86

One man built 28 squares, or 2 lin. ft. per day. The cost of the mattress was $2 90 per square, or $4 17 per lineal foot.

UPPER-BANK REVETMENT WORK, DELTA POINT, 1881 TO 1883.

Items.	Amount. Per square.	Amount. Per lineal foot.	Cost. Per square.	Cost. Per lineal foot.
Brush, cords	.4	.3	$1 01	$0 76
Poles, number	2.0	1 5	64	48
No. 12 wire, pounds	5.0	3.75	25	19
Spikes, 6-in., pounds	.8	.6	04	03
Rock, cubic yards	2.0	1.5	3 80	2 85
Labor	...	....	1 15	86

One man built $1\frac{1}{2}$ squares or 2 lin. ft. per day. The cost per square was $6 89, and the cost per lineal foot was $5 17. The mat and upper-bank revetment cost about $4 05 per square or $9 34 per lineal foot.

MATS AND REVETMENT, MEMPHIS, 1882 AND 1883; 2 005 SQUARES.

Materials per square: Willow brush, 1.4 cords; cottonwood poles, 2.5 cords; oak pins, 4 ft. by 1 in., 0.35; oak pins, 1 ft. by ¾ in., 1; wire, 1.4 lbs.; stone, 0.54 cu. yds.; sand, 0.1 bag.

HOPEFIELD BEND, 1882 AND 1883.

The following statement gives the distribution of material in 1 127 lin. ft. of mattress 140 ft. wide, 194 x 25 ft. of foot mat, and 194 x 16 ft. of upper-bank revetment; 1 657 squares in all. Willow brush, 840 cords, 0.5 cord per square; poles, 105 cords, 0.1 cord per square; wire, 2 534 lbs., 1.5 lbs. per square; rope, 80 lbs., 0.05 lbs. per square; spikes, wrought, 1 950 lbs., 1.2 lbs. per square; nails, 200 lb., 0.12 lb. per square; stone, 585 cu. yds., 0.35 cu. yd. per square; gunny bags, each containing 120 lbs. of clay, 4 300, 2.6 per square.

LAKE PROVIDENCE, 1882 AND 1883; MATS AND BRUSH REVETMENT, 250 SQUARES OR 100 LIN. FT.

	Amount.		Cost.	
Items.	Per square.	Per lineal foot.	Per square.	Per lineal foot.
Brush, cords	.61	1.54	$1 07	$2 69
Stone, cubic yards	.41	1 02	82	2 04
Poles, cords	.05	.12	10	25
Spikes, pounds	.51	1.27	02	06
Wire, pounds	.89	2.23	06	16
Iron rods, pounds	4.00	10.00	20	50
Towing	....	.....	33	83
Labor	....	......	1 87	4 67
Total cost			$4 47	$11 20

The mats were 250 ft. wide; the foot mats, 40 ft.; the revetment, 60 ft.

PLUM POINT REACH, 1884.

Mat, 175 x 2 010 ft.; 3 517 squares.

Materials.	Total amount.	Per square.	Per lineal foot.
Brush, cords	1 741.41	0.49	0.86
Poles, cords	198.70	0.05	0.09
Wire, pounds	9 175	2.61	4.56

Mat, 175 x 1 750 ft.; 3 062 squares.

Materials.	Total amount.	Per square.	Per lineal foot.
Brush, cords	1 417.75	0.46	0.81
Poles, cords	149.5	0.05	0.08
Wire, pounds	8 650.0	2.82	4.94
Stone, cubic yards	1 757.5	0.57	1.00

Mat, 175 x 1 713 ft.; 2 998 squares.

Materials.	Total amount.	Per square.	Per lineal foot.
Brush, cords	1 982	0.66	1.15
Poles, cords	210	0.07	0.12
Wire, pounds	11 100	3.70	6.48
Stone, cubic yards	1 696	0.57	0.99

MEMPHIS HARBOR, 1884 AND 1885.

The following amounts are for upper-bank and subaqueous work combined, a total of 12 937 squares. The mats were 150 to 250 ft. wide and 1 500 ft. long. Brush, 11 978 cords, 0.93 cord per square; poles, 440 cords, 0.03 cord per square; stone, 13 654 cu. yds., 1.06 cu. yds. per square; wire, 95 142 lbs., 7.36 lbs. per square; wire rope, 14 733 lbs., 1.14 lbs. per square; iron rods, 85 867 lbs., 6.64 lbs. per square; spikes, 22 500 lbs., 1.74 lbs. per square.

HOPEFIELD BEND, 1884 AND 1885.

The following materials were used in constructing 11 003 squares of upper-bank and subaqueous work combined, the mattresses being 150 ft. wide and 2 978 ft. long: Brush, 14 674 cords, 1.33 cords per square; poles, 282 cords, 0.02 cord per square; stone, 6 487 cu. yds., 0.59 cu. yd. per square; wire, 98 090 lbs., 8.91 lbs. per square; spikes, 17 800 lbs., 1.62 lbs. per square; gravel, 3 135 cu. yds., 0.29 cu. yd. per square.

HOPEFIELD BEND, 1885 AND 1886; 2 813 SQUARES, CONTINUOUS AND CONNECTING MATTRESS.

Items.	Amount.	Cost.	Material per square.	Cost per square.
Pay-roll	....	$2 539 92	....	$0 90
Subsistence	....	949 28	....	34
Brush, cords	1 818	2 255 95	.64	80
Poles, cords	171½	291 17	.06	10
Stone, cubic yards	1 620	1 620 00	.58	57
Iron, pounds	8 640	393 76	3.07	14
Wire, pounds	24 310	924 51	8.64	33
Wire rope, feet	4 825	205 06	1.72	08
Spikes and nails, pounds	5 150	165 20	1.83	06
Tug hire	....	35 00	....	01
		$9 379 85		$3 33

The woven mats were 150 ft. wide. The cost of bank covering was $3 85 per square.

HOPEFIELD BEND, 1885 AND 1886; 800 SQUARES UPPER-BANK REVETMENT AND GRADING.

Items.	Amount.	Cost.	Material per square.	Cost per square.
Pay-roll	....	$1 994 28	....	$2 49
Subsistence	....	639 00	....	80
Brush, cords	1 114	1 371 55	1.39	1 71
Poles, cords	80	135 83	.10	17
Stone, cubic yards	882	882 00	1.10	1 10
Iron, pounds	1 822	57 43	2.28	07
Wire, pounds	11 260	435 42	14.07	55
Spikes and nails, pounds	2 350	64 80	2.94	08
Coal, bushels	892½	89 25	1.11	00
Miscellaneous	....	1 75	....	11
		$5 671 31		$7 08

This does not include the cost of general repairs, administration, etc. The area was 1 140 ft. long and 70 ft. wide.

MEMPHIS DIKE CONSTRUCTION, 1886 AND 1887.

Subaqueous or Foundation Mattress, 3 524 squares.

Items.	Amount.	Cost.	Amount per square.	Cost. per square.
Labor	......	$4 196 27	....	$1 19
Subsistence............	......	....	....	....
Brush, cords...........	2 208.6	2 164 43	.63	62
Poles, cords...........	465.5	632 17	.13	18
Stone, cubic yards.....	1 997.7	2 188 44	.57	62
Spikes, pounds........	4 000	104 00	1.13	03
Iron, pounds..........	1 035	18 98	.30	01
Lumber, feet..........	6 884	94 28	1.95	02
Manilla rope, pounds..	4 154	465 32	1.18	13
Miscellaneous..........	......	110 78	....	03
Wire, pounds..........	18 500	740 00	5.22	21
Wire cable, pounds....	10 500	459 37	2.98	13
		$11 174 04		$3 17

MEMPHIS DIKE CONSTRUCTION, 1886 AND 1887.

1 112 Squares of Upper Bank Revetment.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$2 239 58	....	$2 02
Subsistence............	....	....	....	..
Brush, cords...........	1 550	1 667 68	1.39	50
Poles, cords...........	145	189 70	.13	17
Stone, cubic yards.....	1 190	1 304 76	1.07	1 16
Spikes, pounds........	2 700	81 00	2.43	07
Wire, pounds..........	6 704	268 16	6.03	25
		$5 750 88		$5 17

These amounts do not include grading for the shore cribs.

MEMPHIS DIKE CONSTRUCTION, 1886 AND 1887.

1 003 898 Cu. Ft. of Cribwork.

Items.	Amount.	Cost.	Amount per cubic foot.	Cost per cubic foot.
Labor.................	....	$10 159 56	....	$ .01
Brush, cords...........	4 003	3 933 20	.004	.004
Poles, cords...........	987	1 292 11	.0009	.001
Stone, cubic yards	4 494	4 929 54	.005	.005
Spikes, pounds.........	13 553	383 89	.01	.0004
Miscellaneous	....	155 74	....	.0002
Wire, pounds..........	42 824	1 712 96	.04	.002
Wire cable, pounds.....	25 675	1 123 28	.02	.001
Iron, pounds....	7 260	153 11	.007	.0001
		$23 843 39		$0.024

Memphis, 1886 and 1887, Subaqueous Mattress; 7 856 Squares or 2 950 Lin. Ft.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$8 358 03	....	$1 06
Subsistence	....	400 33	....	05
Brush, cords	5 054	5 620 04	.64	72
Poles, cords	765	1 197 50	.09	15
Stone, cubic yards	4 195	7 073 61	.53	90
Wire, pounds	38 498	1 539 92	4.90	20
Wire cable, pounds	15 693	697 98	2.00	08
Spikes and nails, pounds	7 700	207 45	.98	03
Iron, pounds	5 477	148 01	.70	02
Lumber, feet	9 044	150 78	1.15	02
Manilla rope, pounds	2 360	264 50	.30	03
Coal, boxes	200	75 00	.02	01
Miscellaneous	....	113 60	....	02
		$25 846 75		$3 29

The cost per lineal foot of this continuous mattress was $8 76. Including repairs to plant, all office and administration expenses, etc., it was $4 52 per square and $11 97 per lineal foot.

Hopefield Bend, 1887 and 1888, Subaqueous Mattress; 7 546 Squares.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$5 491 95	....	$0 73
Subsistence	....	2 241 80	....	30
Brush, cords	3 752	4 314 80	.50	57
Poles, cords	833	1 457 75	.11	19
Stone, cubic yards	3 821	5 784 96	.50	76
Wire, pounds	39 708	1 588 32	5.25	21
Wire strand, pounds	11 530	547 67	.153	07
Spikes and nails, pounds	6 900	205 45	.91	03
Lumber, feet	3 100	62 00	.41	01
Iron, pounds	1 130	29 75	.15	003
Manilla rope, pounds	1 200	135 00	.16	01
Miscellaneous	....	24 28	....	003
		$21 883 73		$2 89

Hopefield Bend, 1887 and 1888, Upper-Bank Revetment, Including Grading; 6 182 Squares.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$8 092 72	....	$1 31
Subsistence	....	2 907 74	....	47
Brush, cords	5 470	6 521 94	.88	1 05
Poles, cords	603	1 031 65	.10	17
Stone, cubic yards	4 032	6 103 42	.65	99
Wire, pounds	34 678	1 387 12	5.61	.22
Wire strand, pounds	1 450	68 88	.24	01
Spikes and nails, pounds	2 400	73 20	.39	01
Coal, boxes	2 103	787 20	.34	13
Iron, pounds	915	22 77	.15	003
Miscellaneous	....	125 79	....	02
		$27 122 43		$4 38

HOPEFIELD BEND, 1888 AND 1889, SUBAQUEOUS MATTRESS, 196 FT. WIDE; 9 394 SQUARES.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$8 191 35	....	$0 87
Subsistence	....	2 958 86	....	32
Brush, cords	4 977	6 125 60	.53	65
Poles, cords	678	1 185 50	.07	13
Stone, tons	4 442	6 973 94	.47	74
Wire, pounds	48 814	1 911 83	5.20	20
Wire strand, pounds	12 620	534 98	1.34	06
Spikes, pounds	3 300	90 81	.35	01
Lumber, feet	6 325	104 61	.67	01
Iron, pounds	1 623	40 57	.17	004
Manilla rope, pounds	1 650	184 80	.18	02
Miscellaneous	....	43 22	....	005
		$28 346 07		$3 02

HOPEFIELD BEND, 1888 AND 1889, UPPER-BANK REVETMENT, ABOUT 142 FT. WIDE; 6 635 SQUARES COVERED.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$8 572 37	....	$1 30
Subsistence	....	3 095 92	....	47
Brush, cords	6 233	7 885 20	.94	1 19
Poles, cords	621	1 131 75	.09	17
Stone, tons	5 089	7 989 73	.77	1 20
Wire, pounds	53 095	1 821 38	8.00	27
Wire strand, pounds	336	13 43	.05	002
Spikes, pounds	2 000	58 04	.30	01
Manilla rope, pounds	400	44 80	.06	007
Miscellananeous	....	21 34	....	003
		$30 633 96		$4 62

The above does not include grading.

BOLIVAR, 1888 AND 1889.

This work comprised 10 300 squares of mattress, 180 to 250 ft. wide, and 2 842 squares of upper-bank revetment. The amount of materials was as follows: Brush, 9 639 cords, 0.73 cord per square; poles, 1 659 cords, 0.12 cord per square; stone, 10 154 cu. yds., 0.77 cu. yd. per square; wire, 129 310 lbs., 984 lbs. per square; wire cable, 25 025 lbs., 1.9 lbs. per square; spikes, 33 100 lbs., 2.52 lbs. per square; iron rods, 51 924 lbs., 3.95 lbs. per square; clevises, lap rings, 8 500 lbs., 0.65 lb. per square; lumber, 7 081 ft., 0.54 ft. per square; staples, 1 858 lbs., 0.01 lb. per square.

HICKMAN HARBOR, 1889 AND 1890, 2 736 SQUARES OF SUBAQUEOUS MATTRESS, 300 FT. WIDE.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	.....	$3 637 99	....	$1 33
Subsistence	.....	104 78	....	04
Brush, cords	1 812	1 902 60	.66	70
Poles, cords	250	312 50	.09	12
Stone, cubic yards	1 717	2 508 14	.62	91
Wire, pounds	22 560	621 83	8.22	22
Wire strand, pounds	4 061	1 45 79	1.48	05
Spikes and nails, pounds	1 000	27 50	.36	01
Lumber, feet	6 985	75 10	2.56	03
Iron, pounds	1 480	20 60	.54	01
Manilla rope, pounds	700	72 55	.25	02
Piling, feet	455	36 40	.17	02
		$9 465 78		$3 46

HICKMAN HARBOR, 1889 AND 1890, 1 378 SQUARES OF UPPER-BANK REVETMENT, 143 FT. WIDE, GRADING INCLUDED.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	.....	$4 571 41	....	$3 31
Subsistence	.....	305 00	....	22
Brush, cords	1 317	1 382 85	.95	1 00
Poles, cords	131	163 50	.09	1185
Stone, cubic yards	1 508	2 202 90	1.095	1 60
Wire, pounds	5 524	155 10	4.01	1135
Spikes and nails, pounds	300	8 25	.22	006
Lumber, feet	1 000	15 00	.725	011
Coal, bushels	2 292	229 20	1.662	166
Oil, etc	.....	76 58	....	055
		$9 109 79		$6.000

The total revetment on this work, above and below water cost, including charges on plant, etc., $6 00 per square and $24 77 per lineal foot.

LOUISIANA BEND, 1889.

This work comprised 21 695 squares of subaqueous mattress and 5 672 squares of paving, 10 ins. thick. The materials used were as follows: Stone, 48 161 cu. yds., 1.76 cu. yds. per square; brush, 18 813 cords, 0.68 cord per square; poles, 3 362 cords, 0.12 cord per square; wire, 167 440 lbs., 6.16 lbs. per square; wire cable, 329 560 lbs., 12.02 lbs. per square; spikes, 36 961 lbs., 1.35 lbs. per square.

GREENVILLE, 1889; DIKE NO. 2.

Foundation Mattress, 290 x 290 Ft. or 841 Squares.

Materials.	Amount.	Cost per unit.	Cost, total.	Amount per square.	Cost per square.
Brush, cords	553	$1 27½	$705 07	0.657	$0 84
Poles, cords	141	1 47½	207 97	0.168	25
Stone, tons	767	1 95	1 496 65	0.912	1 78
Wire, coils	34	3 37	114 58	0.040	14
Cable, coils	6	42 27	253 62	.007	30
Spikes, 6-in., kegs	4	3 25	13 00	....	..
Spikes, 9-in., kegs	5½	3 12½	15 63	.011	03
Staples, kegs	1¼	5 00	6 25	.001	01
Total materials			$2 811 77		$3 35
Labor, hours, including subsistence	5 630	16	$900 80	6.69	$1 07
Sailor work, hours, including subsistence	737	16	117 92	0.88	14
Total labor			$1 018 72		$1 21
Grand total			$3 830 49		$4 56

Crib No. 1, 212 32 x 8 Ft.; 54 272 Cu. Ft.

Materials.	Amount.	Cost per unit.	Cost, total.	Amount per 100 cubic feet.	Cost per 100 cubic feet.
Brush, cords	228	$1 27½	$290 70	.420	$0 54
Poles, cords..........	100	1 48	148 00	.184	27
Stone, tons	324	1 50	486 00	.597	90
Wire, coils......... ..	32	3 37	107 84	.059	20
Cable, coils..........	2½	42 27	105 67	.005	20
Spikes, 6-in., kegs....	2¾	3 25	8 94	....	..
Spikes, 9-in., kegs ...	7¾	3 12½	24 22	.013	05
Total material cost.			$1 171 37		$2 16
Labor, hours, including subsistence.....	2 686	16	$429 76	4.95	$0 79
Sailor work, hours, including subsistence.	610	16	97 60	1.12	18
Total.............			$527 36		$0 97
Grand total.......			$1 698 73		$3 13

Crib No. 2, 170 x 16 x 8 Ft.; 21 760 Cu. Ft.

Materials.	Amount.	Cost per unit.	Cost, total.	Amount per 100 cubic feet.	Cost per 100 cubic feet.
Brush, cords.........	95	$1 27½	$121 12	.437	$0 55
Poles, cords..........	52	1 48	76 96	.239	35
Stone, tons...........	119	1 95	232 05	.547	1 08
Wire, coils...........	27	3 37	90 99	.124	42
Cable, coils..........	1½	42 27	63 40	.007	29
Spikes, 6-in., kegs....	1¾	3 25	5 69	....	..
Spikes, 9-in., kegs....	2¼	3 12½	7 03	....	..
Spikes, 9-in., kegs....	1½	5 70	8 55	.002	09
Total			$605 79		$2 78
Labor, including subsistence, hours.....	1 351	16	$216 16	6.21	$0 99
Sailor work, including subsistence, hours..	310	16	49 60	1.42	23
Total			$265 76		$1 22
Grand total.......			$871 55		$4 00

Revetment, 230 Squares.

Materials.	Amount.	Cost per unit.	Total cost.	Amount per square.	Cost per square.
Brush, cords	325	$1 09	$354 25	1.413	$1 54
Poles, cords..........	45	1 48	66 60	.196	29
Stone, tons...........	649	1 95	1 265 55	2.822	5 50
Wire, coils...........	22	3 37	74 14	.096	32
Spikes, 6-in., kegs....	½	3 25	1 62	....	..
Spikes, 9-in., kegs....	3	3 12½	9 37	....	..
Spikes, 9-in., kegs....	½	5 70	2 85	.017	06
Total material....			$1 774 38		$7 71
Grading, labor and subsistence, hours..	5 000	16	$800 00	21.74	$3 48
Construction, labor and subsistence, hours..............	3 584	16	593 44	15.58	2 58
Total			$1 393 44		$6 08
Grand total.......			$3 167 82		$13 77

Land Crib, 3 000 cu. ft.

	Amount.	Cost per unit.	Total cost.	Amount per 100 cubic feet.	Cost per 100 cubic feet.
Brush, cords	7	$1 09	$7 63	.233	$0 25
Poles, cords	10	1 48	14 80	.333	49
Stone, cords	16	1 95	31 20	.533	1 04
Wire, coils	2	3 37	6 74	.066	22
Total materials..			$60 37		$2 00
Labor, including subsistence, hours		16	32 32	6.073	1 08
Grand total.....			$92 69		$3 08

NEW ORLEANS HARBOR, 1890 AND 1891.

Foundation Mat, 355 x 130 x 1.75 Ft., or 461 Squares.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Brush, cords	608	$1 258 35	1.32	$2 73
Lumber, feet	16 222	176 80	3.51	38
Rock, tons	299	597 34	.65	1 30
Wire, pounds	991	39 64	2.15	08
Nails, pounds	4 200	132 90	9.12	29
Chain, pounds	3 787	132 54	8.240	28
Bolts, number	86	4 30	·18	01
Fish plates, number ...	131	9 17	.28	02
Subsistence		360 00	....	78
Labor		1 995 91	....	4 33
Total		$4 706 95		$10 20

Cribs, 2 325 Cu. Ft.

Brush, 1 387 cords, costing $2 870 67; poles, 68 cords, costing $140 76; rock, 580 tons, costing $1 160 09; lumber, 37 380 ft., costing $407 44; No. 10 wire, 2 090 lbs., costing $83 60; iron rods, 456 lbs., costing $15 96; nails, 2 150 lbs., costing $74 25; subsistence, $450; labor, $3 100 16. Total cost, $8 303 74; cost per cubic foot, 3.57 cents.

ASHBROOK NECK, 1891 AND 1892, MATTRESSES 300 FT. WIDE AND UPPER-BANK PAVING.

This work required the following materials: Brush and poles, 2.565 cords per lineal foot; stone, 5.136 cu. yds.; wire cables, 14.8 lbs.; wire, 19.517 lbs.; spikes, 2.6 lbs. The distribution per square was as follows: Brush, 0.661 cord; poles, 0.132 cord; stone, 0.688 cu. yd. The cost per unit is given in the tabular statement immediately following.

	Labor and subsistence.	Material.	Total.
Mat work, per square	$1.573	$3.117	$4.690
Foot mat, per square	1.719	3.616	5.333
Revetment, per square	2.388	6.809	9.197
Paving, per square	1.617	7.006	8.623
Clearing bank, per acre	71.500	.....	71.50
Loading stone, per cubic yard	0.589	.....	0.589
Grading, per lineal foot	0.840	0.369	1.210
Dressing, per lineal foot	0.457	.....	0.457

GREENVILLE, 1891 AND 1892; 300-FT. WOVEN MAT AND PAVING.

Kind of work.	Cost per Unit. Labor and subsistence.	Material.	Total.
Mattress, per square	$1.332	$3.167	$4.499
Revetment, per square	2.042	7.502	9.544
Paving, per square	1.121	7.474	8.594
Grading, per lineal foot	.5387	.213	.7523
Dressing, per lineal foot	.0755	.00	.6755
Loading stone, per cubic yard	.4520	.003	.4550

LOUISIANA BEND, 1891 AND 1892, 270-FT. MATS AND 10-IN. PAVING.

Materials.	Mattress.	Connecting mat.	Upper-bank revetment.	Paving.
Brush, cords	0.8	0.8	1.2	
Poles, cords	.12	.12	.12	
Stone, cubic yards	.7	1.25	1.25	3.00
Wire, pounds	5.2	5.2	5.2	
Cable, pounds	4.4	4.4	4.4	
Spikes, pounds	0.16	0.16		

PLUM POINT REACH, 1892 AND 1893.

River Mattress, Heaviest Woven Type.—Brush, 0.948 cord per square; poles, 0.111 cord; stone, 0.647 cu. yd.; wire, 8.07 lbs.; wire strand, 2.9 lbs.; spikes, 0.4 lb.; cable clamps, 0.114; staples, 0.048 lb.; piles, 0.0092.

Paving.—Stone, 0.385 cu. yd. per square, and 1.709 cu. yds. per lineal foot; spalls, 0.113 and 0.501 cu. yd.

Connecting Mats.—Brush, 1.117 cords per square; poles, 0.136 cord; stone, 2.228 cu. yds.; wire, 6.716 lbs.; wire strand, 2.024 lbs.; spikes, 0.24 lb.; cable clamps, 0.0078; staples, 0.0012 lb.

Pocket Mats.—Brush, 0.83 cord per square; poles, 0.145 cord; stone, 1.55 cu. yds.; wire, 7.44 lbs.; wire strand, 2 lbs.; clamps, 0.065; staples, 0.025 lb.; spikes, 0.206 lb.

Cost of Work.—River mats, $4.27 per square; connecting mats, $8.17 per square; pocket mats, $5.90 per square; paving, $10.11 per square; grading, 3¾ cents per cubic yard; clearing, $42.56 per acre. Cost per lineal foot of revetment complete, $19.22.

ASHBROOK NECK, 1892 AND 1893.

The mattress in this work was 250 ft. wide, and the slope of the paved bank was 4 to 1. The distribution of the materials was as follows: Brush, 0.62 cord per square, 2.025 cords per lineal foot; poles, 0.14 cord per square, and 0.41 cord per lineal foot; stone, 6.137 cu. yds. per lineal foot; wire, 7.7 lbs. per square, and 22.95 lbs. per lineal foot; wire cable, 4 and 13.6 lbs. This work cost $29 07 per lineal foot.

GREENVILLE, 1892 AND 1893.

This work included woven mattresses and a paved upper bank on a slope of 4 to 1. The distribution of materials was as follows: Brush, 0.71 cord per square and 2.55 cords per lineal foot; poles, 0.13 and 0.35 cord; stone for mattress, 0.63 cu. yd. per square; stone for paving, 3.03 cu. yds. per square; total stone, 5.74 cu. yds. per lineal foot; wire, 5.36 lbs. per square, and 20.98 lbs. per lineal foot; wire cable, 4.28 and 14.92 lbs. The work cost $27 08 per lineal foot.

Louisiana Bend, 1892 and 1893.

The work comprised woven mats and upper-bank paving. The distribution of materials was as follows: Brush, 0.88 cord per square and 2.63 cords per lineal foot; poles, 0.17 and 0.44 cord; stone for mat, 0.63 cu. yd. per square; stone for paving, 3.58 cu. yds. per square; total stone, 6.25 cu. yds. per lineal foot; wire, 5.61 lbs. per square and 20.14 lbs. per lineal foot; wire cable, 3.53 and 10.69 lbs.

Bolivar Front, 1893.

This work was a mat 300 ft. wide, 2 ft. thick at the upper edge and 1 ft. at the lower. The distribution of the materials was as follows: Brush, 0.98 cord per square; poles, 0.15 cord; stone, 0.53 cu. yd.; wire, 5.5 lbs.; wire cable, 4.29 lbs.; spikes, 0.75 lb.

Hopefield Bend, 1893 and 1894.

The work included a fascine mattress 310 ft. wide and connecting fascine mattresses. The material in the 310-ft. mattress was distributed as follows: Brush, 1.639 cords per square; poles, 0.053 cord; stone, 0.625 ton; steel wire, 4.861 lbs.; copper wire, 0.546 lbs.; wire strand, 10.965 lbs.; clamps, 1.5. The cost per square constructed was $5 94 and the cost per square of bank covered was $6 07. The distribution of the material in the connecting mattresses was as follows: Brush, 2.355 cords per square; poles, 0.122 cord; stone, 0.66 ton. The cost was $6.987 per square.

Distribution of Material, 1894.

Material.	Ashbrook Neck.	Greenville.	Lake Providence.
Brush per square, woven mat, cords	1.163	1.157	0.98
Brush per square, fascine mat, cords	....	....	1.37
Poles per square, woven mat, cords	0.214	0.200	0.14
Stone per lineal foot, cubic yards	6.76	6.66	7.3
Wire per lineal foot, pounds	28.35	30.63	25.38
Wire strand per lineal foot, pounds	15.03	16.00	25.54
Spikes per lineal foot, pounds	4.47	3.20	1.89

APPENDIX B.—Cost of Bank Protection Work, Per Unit, from 1878 to 1895.

Date.	Locality.	Mattress work. Per square.	Connecting mat. Per square.	Upper-Bank Revetment, Including Grading. Brush work. Per square.	Upper-Bank Revetment, Including Grading. Stone paving. Per square.	Crib work. Per cubic foot.	Mat and upper bank work combined. Per square.	Complete work. Per lineal foot.	Remarks.
1878	New Orleans Harbor	$12 87							Cane mats, 200′ x 24′.
1879	" " "	9 88						$13 38	" " "
1879	Delta Point, La.	12 00						18 00	Pin mats, 150′ x 50′.
1880	New Orleans Harbor	7 22							Cane mats, 200′ x 70′.
1882	Delta Point, La.	2 90		$6 89				14 00	Woven mats, 140′ x 400′.
1883	Plum Point Reach	6 30		6 40					Woven mats and brush revetment.
1882-1883	Lake Providence Reach						$4 47	11 20	Woven mats and brush revetment.
1884	New Orleans Harbor	7 60				$0 03⅓			Woven mats, 200′ x 350′, framed cribs.
1885-1886	Hopefield Bend	3 85		7 08					Woven mats, 150′ wide, brush revetment.
1886-1887	Memphis Harbor	3 17		5 17		.024			Woven mats, frame cribs, including grading.
1886-1887	" "	3 29							Woven mats, continuous revetment.
1887-1888	Hopefield Bend	2 89		4 38					Woven mats, continuous revetment.
1888	Greenville Harbor							20 20	Dike construction.
1888	New Orleans Harbor	7 54 and 9 11				.0457			Woven mats and cribs.
1888	Hopefield Bend						4 75		Woven mats, brush revetment.
1888	Bolivar Front						9 26	28 31	Woven mats, brush revetment.
1888-1889	Hopefield Bend	3 02		4 62					Woven mats, brush revetment.
1889	New Orleans Harbor	6 39							Woven mats.
1889	" " "	9 56				.04			Frame mats, frame cribs.

	Hickman Harbor	3 46		6.00				24 77	Woven mats, brush revetment.
	Columbus Harbor					.04	6 70	22 65	Woven mats and cribs.
1889-1890	Helena Harbor	4 89				.044			Woven mats and cribs.
	Greenville Harbor	4 56		7.71		.031 and .04			Woven mats and cribs.
	Bolivar Front						10 68		Woven mats and brush revetment.
	New Orleans Harbor	10 20				.0357			Pin mats, frame cribs.
1890-1891	Ashbrook Neck						7 69	30 42	Woven mats and brush revetment.
	New Orleans Harbor	9 95 and 9 48				.0358 and .0431			Pin mats and framed cribs.
	Hopefield Bend	7 02	$3 36		6 12			19 57	Paving 10" stone.
	Ashbrook Neck	4 69	5 33	9.197	8 623			30 83	Woven mat pavement, 10".
1891 1892	Greenville Harbor	4 50		9.54	8 59			29 52	" " " "
	Louisiana Bend						6 06	26 49	" " " "
	New Orleans Harbor	9 28				.037			Pin mats, frame cribs.
	Ashport Bend	4 27	8 17 and 5 90		10 11			19 22	Woven mats and paving.
	Daniels Point	5 09	7 81						" " "
	Hopefield Bend	3 65	5 89		11 70				" " "
1892-1893	Ashbrook Neck							29 07	" " "
	Greenville Harbor							27 08	" " "
	Louisiana Bend							27 86	" " "
	New Orleans Harbor	8 92							Pin mats.
	New Madrid Harbor							27 78	Fascine mats and paving.
	Ashport Bend	6 28	11 85		10 11				" " "
1893-1894	Hopefield Bend	6 03	6 99		9 20			31 52	" " "
	Bolivar Front						8 36	25 08	Woven mats and paving.
	Delta Point							26 32	" " "
	Ashbrook Neck							30 25	" " "
	Greenville Harbor							28 22	" " "
1894-1895	Lake Providence							30 41	Woven and fascine mats and paving.

In the finished work the percentage of cost of labor and material is about 45 and 55%, respectively.

Vol. XXII. FEBRUARY, 1896. No. 2.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publication.

CONTENTS.

SOCIETY AFFAIRS.

PAPERS.

ILLUSTRATIONS.

The Proceedings and Transactions will be sent to any subscriber at the rate of $10 per year. Postage will be added when sent to foreign countries.

American Society of Civil Engineers.

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The rooms of the Society are open from 9 to 17 o'clock each business day, except Saturday (when they are closed at 15 o'clock), and at other times on application to the Janitor.

HOUSE OF THE SOCIETY—127 EAST TWENTY-THIRD STREET, NEW YORK.

Vol. XXII. FEBRUARY, 1896. No. 2.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS.

CONTENTS:

REPORT IN FULL OF THE ANNUAL MEETING, JANUARY 15th AND 16th, 1896.

Wednesday, January 15th, 1896.—President George S. Morison in the chair; Charles Warren Hunt, Secretary. **Meeting called to order.**

The PRESIDENT.—The meeting will please come to order. I would request any Past-Presidents who may be present to take seats on the platform.

Before proceeding to any order of business the Secretary has some announcements to make.

The SECRETARY.—The programme for to-day is as follows: At this meeting the annual reports will be presented, officers elected, place for holding the next Annual Convention considered, and any other general Society business transacted. At 13.30 o'clock lunch will be served in the Society House, and, if necessary, this meeting will be resumed. **Programme.**

At 20 o'clock an address, illustrated by stereopticon views, will be delivered in this building by H. W. York, Jun. Am. Soc. C. E., Chief Engineer of the United Electric Light and Power Company, descriptive of the central station recently erected at 407–419 East Twenty-eighth Street, New York City.

Programme (continued).

To-morrow a special train will leave the New York side of the Christopher Street Ferry at 9.30, and Barclay Street Ferry at 9.20 o'clock, and run, *via* the Delaware, Lackawanna and Western Railroad, to Ampere, N. J., where, by invitation of the Crocker-Wheeler Electric Company, S. S. Wheeler, M. Am. Soc. C. E., President, an opportunity will be given for the inspection of the new works of that company. The train will bring the party back in time for lunch at the Society House, which will be served at 13.30 o'clock, after which the afternoon will be free for excursions to various points of interest.

Members and guests have been invited by C. C. Martin, M. Am. Soc. C. E., Superintendent and Chief Engineer, and G. Leverich, M. Am. Soc. C. E., Mechanical Engineer, of the New York and Brooklyn Bridge, to visit that structure, and tickets permitting free transit over the Bridge, as well as permits for examination, may be obtained on application to the Secretary.

While the tickets are good at any time during the meeting, on Thursday afternoon officers of the Bridge will be present to explain the interesting features to Members who may visit the structure.

By invitation of H. W. York, Jun. Am. Soc. C. E., Chief Engineer of the United Electric Light and Power Company, Members and guests will have an opportunity during this afternoon of inspecting the new central station which this company has erected at Nos. 407–419 East Twenty-eighth Street.

A reception and conversazione will be held at Delmonico's, corner of Fifth Avenue and Twenty-sixth Street, at 20 o'clock. Dancing will begin at 21 o'clock, and supper will be served during the evening. Tickets will be necessary in order to secure admission to this reception, and may be obtained on application to the Secretary.

To the meeting this evening and to the excursion, lunch and reception, ladies of the families of Members are cordially invited.

Tellers appointed.

The PRESIDENT.—According to the provisions of the Constitution, the polls will remain open until 12 o'clock, and every Member can vote until that time. In accordance with the usual custom, the tellers will be appointed now, who will at once take charge of the ballots, and any ballots that may be cast before 12 o'clock will be added to those placed in their hands.

I would appoint Mr. Charles J. H. Woodbury, Mr. George W. Bramwell and Mr. Mace Moulton as tellers to canvass the vote for officers.

I would also give notice that a meeting of the newly elected Board of Direction will be held this afternoon. The exact time will be stated when the result of the election is announced.

Report of Board of Direction read.

The first business in order will be the reading of the Annual Report of the Board of Direction, which I will call upon the Secretary to read.

The Secretary read the report.*

* See *Proceedings*, Vol. XXII, p. 7.

The PRESIDENT.—Gentlemen, you have heard the annual report of the Board of Direction. Attached to this report are the customary appendices. The Chair would suggest that the Report of the Treasurer be read in full, and that the previous practice of simply reading the balances of the Auditor's Report be followed, and that the Report of the Finance Committee be read in full. If this is your pleasure, the Secretary will read them in this way.

The Secretary read the Treasurer's Report,* the balances of the Auditor's Report,† and the Report of the Finance Committee.‡

The PRESIDENT.—Gentlemen, you have heard the Annual Report of the Board of Direction; what action will you take with regard to that?

Gen. WILLIAM P. CRAIGHILL.—I may have misunderstood the Secretary, but I want to ask the question as to what was the amount in the Auditor's Report for postage? It struck me as being a very large sum.

The SECRETARY.—$2 313 80.

General CRAIGHILL.—It seemed a very large sum, and I simply wanted to ask if that was the usual expenditure for postage for this Society?

The SECRETARY.—I will give it to you for last year, General; it was $3 790 36.

The PRESIDENT.—For the year 1893, it was $2 164 13.

The SECRETARY.—I should explain that the reason this item was so much greater last year was that we did not have the lower rate during part of the year. During this year we have it.

General CRAIGHILL.—I understood that some effort had been made about a year ago to have a reduction made in the cost of postage for the Society and that this effort had been successful by the passage of a law in Congress. It struck me the amount was still very large.

Mr. HENRY C. MEYER.—Is not a portion of that amount due to the publication of the *Bulletin?*

The SECRETARY.—Yes, some of it is.

The PRESIDENT.—Gentlemen, what action will you take on the report of the Board of Direction? It is before the Society for discussion and for acceptance.

Mr. MENDES COHEN.—I suppose the usual action is to receive the report and place it on file and have it published in the usual manner.

The PRESIDENT.—I believe that the usual action is to accept the report and have it published in the usual manner. Do I understand you to make that motion?

Mr. COHEN.—I make that motion, sir.

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* See *Proceedings*, Vol. XXII, p. 14.
† See *Proceedings*, Vol. XXII, p. 16.
‡ See *Proceedings*, Vol. XXII, p. 22.

Programme (continued). To-morrow a special train will leave the New York side of the Christopher Street Ferry at 9.30, and Barclay Street Ferry at 9.20 o'clock, and run, *via* the Delaware, Lackawanna and Western Railroad, to Ampere, N. J., where, by invitation of the Crocker-Wheeler Electric Company, S. S. Wheeler, M. Am. Soc. C. E., President, an opportunity will be given for the inspection of the new works of that company. The train will bring the party back in time for lunch at the Society House, which will be served at 13.30 o'clock, after which the afternoon will be free for excursions to various points of interest.

Members and guests have been invited by C. C. Martin, M. Am. Soc. C. E., Superintendent and Chief Engineer, and G. Leverich, M. Am. Soc. C. E., Mechanical Engineer, of the New York and Brooklyn Bridge, to visit that structure, and tickets permitting free transit over the Bridge, as well as permits for examination, may be obtained on application to the Secretary.

While the tickets are good at any time during the meeting, on Thursday afternoon officers of the Bridge will be present to explain the interesting features to Members who may visit the structure.

By invitation of H. W. York, Jun. Am. Soc. C. E., Chief Engineer of the United Electric Light and Power Company, Members and guests will have an opportunity during this afternoon of inspecting the new central station which this company has erected at Nos. 407–419 East Twenty-eighth Street.

A reception and conversazione will be held at Delmonico's, corner of Fifth Avenue and Twenty-sixth Street, at 20 o'clock. Dancing will begin at 21 o'clock, and supper will be served during the evening. Tickets will be necessary in order to secure admission to this reception, and may be obtained on application to the Secretary.

To the meeting this evening and to the excursion, lunch and reception, ladies of the families of Members are cordially invited.

Tellers appointed. The President.—According to the provisions of the Constitution, the polls will remain open until 12 o'clock, and every Member can vote until that time. In accordance with the usual custom, the tellers will be appointed now, who will at once take charge of the ballots, and any ballots that may be cast before 12 o'clock will be added to those placed in their hands.

I would appoint Mr. Charles J. H. Woodbury, Mr. George W. Bramwell and Mr. Mace Moulton as tellers to canvass the vote for officers.

I would also give notice that a meeting of the newly elected Board of Direction will be held this afternoon. The exact time will be stated when the result of the election is announced.

Report of Board of Direction read. The first business in order will be the reading of the Annual Report of the Board of Direction, which I will call upon the Secretary to read.

The Secretary read the report.*

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* See *Proceedings*, Vol. XXII, p. 7.

The PRESIDENT.—Gentlemen, you have heard the annual report of the Board of Direction. Attached to this report are the customary appendices. The Chair would suggest that the Report of the Treasurer be read in full, and that the previous practice of simply reading the balances of the Auditor's Report be followed, and that the Report of the Finance Committee be read in full. If this is your pleasure, the Secretary will read them in this way.

The Secretary read the Treasurer's Report,* the balances of the Auditor's Report,† and the Report of the Finance Committee.‡

The PRESIDENT.—Gentlemen, you have heard the Annual Report of the Board of Direction; what action will you take with regard to that?

Gen. WILLIAM P. CRAIGHILL.—I may have misunderstood the Secretary, but I want to ask the question as to what was the amount in the Auditor's Report for postage? It struck me as being a very large sum.

The SECRETARY.—$2 313 80.

General CRAIGHILL.—It seemed a very large sum, and I simply wanted to ask if that was the usual expenditure for postage for this Society?

The SECRETARY.—I will give it to you for last year, General; it was $3 790 36.

The PRESIDENT.—For the year 1893, it was $2 164 13.

The SECRETARY.—I should explain that the reason this item was so much greater last year was that we did not have the lower rate during part of the year. During this year we have it.

General CRAIGHILL.—I understood that some effort had been made about a year ago to have a reduction made in the cost of postage for the Society and that this effort had been successful by the passage of a law in Congress. It struck me the amount was still very large.

Mr. HENRY C. MEYER.—Is not a portion of that amount due to the publication of the *Bulletin?*

The SECRETARY.—Yes, some of it is.

The PRESIDENT.—Gentlemen, what action will you take on the report of the Board of Direction? It is before the Society for discussion and for acceptance.

Mr. MENDES COHEN.—I suppose the usual action is to receive the report and place it on file and have it published in the usual manner.

The PRESIDENT.—I believe that the usual action is to accept the report and have it published in the usual manner. Do I understand you to make that motion?

Mr. COHEN.—I make that motion, sir.

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*See *Proceedings*, Vol. XXII, p. 14.
† See *Proceedings*, Vol. XXII, p. 16.
‡ See *Proceedings*, Vol. XXII, p. 22.

The motion was carried.

Norman Medal Report.

The PRESIDENT.—The next regular business in order is the report of the Board of Censors appointed to award the Norman Medal. I will call upon Prof. Ricketts, a member of that Board, to read the report.

Prof. Ricketts read the report.*

The PRESIDENT.—Gentlemen, you have heard the report of the Board of Censors to Award the Norman Medal. The next report in order is the report of the Committee to Award the Rowland Prize. As none of the Committee are present I will call upon the Secretary to read this report.

Rowland Prize Report.

The SECRETARY.—With the exception of the Secretary, there is no member of the Committee present. The report of the Committee to Award the Rowland Prize is in the form of a letter to the Secretary from the Chairman of the Committee.

The Secretary read the letter.†

The PRESIDENT.—Gentlemen, you have heard the report of the Committee to Award the Rowland Prize. The prize will be awarded in accordance with this report.

Report on Time and place for Convention.

The next business in order is the report on the vote for the place of holding the Annual Convention.

The SECRETARY.—Three hundred and sixteen votes have been received for the place of holding the next Annual Convention, distributed as follows :

New York City	30
San Francisco	29
Chicago	23
St. Louis	18
Washington	17
Pittsburg	14
Philadelphia	14
Detroit	12
Buffalo	11
Denver	10
Saratoga	8
Cleveland	8
New Orleans	8
Duluth	7
Montreal	7
Baltimore	5
White Sulphur Springs	5
Great Lakes	5
Halifax	4

* See *Proceedings*, Vol. XXII, p. 4.

† See *Proceedings*, Vol. XXII, p. 4.

The rest scattering, with seven additional votes for places on the Pacific coast.

The PRESIDENT.—Gentlemen, you have heard the result of the canvass of the votes with regard to the holding of the Annual Convention. The subject of the Annual Convention is now before the house for discussion.

Mr. EDWARD P. NORTH.—I move that that be referred, as usual, to the Board of Direction.

Mr. T. GUILFORD SMITH.—Before that motion is put, I trust very much that the Members who are present will assist the Board of Direction by giving some indication of their views in addition to those given by letter, as we often feel very much puzzled to know how to meet their wishes without the discussion which has been usually held at this time. I have no preference myself for any particular spot.

The PRESIDENT.—The Chair will rule that any remarks which any Member present may see fit to make as to the time and place of this Annual Convention are in order as part of the discussion of Mr. North's motion.

Mr. BENJAMIN M. HARROD.—I would like to ask if this reference to the Board of Direction conveys with it the power to act?

The PRESIDENT.—It does. The subject is now before the house in such a way that any Member can give his individual preference and his reasons. We should be glad to hear from any one who has any special information.

Mr. JOSEPH M. KNAP.—It is my view, Mr. President, that we should have our next convention in the West.

The PRESIDENT.—The largest number of votes, I believe, is for New York City, the place at which the Annual Meeting is held every year. The next largest number of votes is for San Francisco, and if the votes of California are added the result is practically the same as for New York City.

The SECRETARY.—It comes to considerably more. There is only a difference of one vote between New York and San Francisco, and if the seven scattering votes for far western places are added, San Francisco would be six votes ahead.

Mr. P. ALEX. PETERSON.—I do not think the number of votes expresses by any means the feeling of the Society at large. I voted for Quebec. I think a great many Members of the Society would like to go to Quebec. A new hotel is being built there, a very fine hotel, and the Convention could be held at a time before travel commences. I have seen the managers of the hotel and they say that they would be able to accommodate the whole Society, and certainly anybody who has been in Quebec knows that it is in a most charming place, and I am certain that the Members of the Society if they went to Quebec once would want to go there again.

Discussion on Time and place for Convention (continued).

The PRESIDENT.—If the Chair may reply to the remarks of Mr. Peterson, I would like to say that I think there is no place which can be found in North America which offers greater inducements for an attractive convention than the city of Quebec. I have not been there for over 30 years. On the other hand it must be remembered that the last two conventions have been held in the eastern part of the country, and the last one almost as far east as Quebec, and while under other circumstances it would appear that there would be no better place, there may be much better reasons for going there a year hence than the present year.

General CRAIGHILL.—I would like to ask how many members there are in our Society west of the Rocky Mountains.

The PRESIDENT.—Mr. Secretary, can you answer that question?

The SECRETARY.—I could not answer that unless I counted them up.

A MEMBER.—I think really the important question to know is how many Members of the Society would go to the Pacific coast. It is a long distance and it takes a good while.

Prof. RICKETTS.—Might it not also be a question how many of the votes come from Members west of the Rocky Mountains, or Denver and west of that, whether those votes were from Members in the East, or whether they were from western Members?

The SECRETARY.—I think in round numbers they were about half and half. I think of the 40 or 45 votes that were cast for Denver and points further west, about one-half came from that region.

Mr. CROES.—Has there been any special desire manifested by the members west of the Rocky Mountains or by other organizations outside of the Society in a certain district of country to have the Society visit that place ?

The PRESIDENT.—I do not think that any special request has as yet come from the Pacific coast. Neither do I think that there has generally been a formal request as early as this. If this matter is referred to the Board of Direction, if Mr. North's motion passes, the Board of Direction will undoubtedly consider the matter in precisely the view raised by Mr. Croes, and unless there is a wish on behalf of organizations of members on the Pacific coast that we should go there, I do not think the Board of Direction would decide to go.

Mr. CHARLES FRANCIS.—I would like to ask if the Convention has ever been held in Denver.

The PRESIDENT.—It has. It has never been held west of Denver. Are there any further remarks on this subject ?

The SECRETARY.—There are more than 100 Members of the Society residing in the Rocky Mountain and Pacific region, say west of Denver.

The PRESIDENT.—It appears to the Chair that it could not be expected that a convention held in the extreme west could be as largely

attended as the late conventions. On the other hand, it is to be considered whether it is not time to have some actual representation of our life in this way, in a region where we have quite a number of Members, though the attendance might be less. Are there any further remarks on the subject? If not, Mr. North's motion will be put. Mr. North's motion is that the matter of the time and place of the Annual Convention be referred to the Board of Direction for final action in the usual manner.

The motion was put and carried.

The PRESIDENT.—The next business in order are the reports of the special committees. There is no formal report from any one of these committees. There are informal reports from each of the three. I will call on the Secretary to read the report of the Committee on Uniform Standard Time.

Report of Committee on Standard Time

The SECRETARY.—I have received two letters from the Chairman of that Committee. The first is dated Ottawa, December 31st, 1895:

CHAS. WARREN HUNT, Esq.,

Secretary American Society Civil Engineers.

Dear Sir,—I should have written you sooner in reply to your letter of November 15th, but in the hope of having something special to communicate, I deferred writing, and by some mischance the matter escaped me until now when I am trying to dispose of my unanswered letters before the year finally closes.

There will be no regular report this year. I will, however, mention two matters, lest any questions be asked at the Annual Meeting.

First.—Standard time is now adopted throughout the Australian continent precisely on the same principle and on the same basis as in North America. Necessarily the hours are numbered differently owing to the difference in longitude, but when an hour is struck with us the clocks strike at the same moment in Australia. The other subdivisions of time are in all respects identical in both continents.

Second.—Means have been taken to bring about the adoption throughout the world of the sixth resolution of the Washington International Conference of 1884. A good deal of difficulty has been experienced, involving much correspondence, but good progress has been made. The adoption of the resolution by the maritime powers will practically abolish reckoning by astronomical time, and the substitute will be civil time for all purposes of reckoning at sea. It has been now ascertained that a degree of unanimity has been reached which warrants the expectation that the change will be effected at an early day, by concerted action among the nations.

Thus it will be seen that the reform in time-reckoning to a large extent initiated by the American Society of Civil Engineers, and which for the last 15 years this Society has done so much to promote, continues to make substantial progress throughout the world. We have every reason to believe that before long the unification of time will practically be complete.

Yours very truly,

SANDFORD FLEMING.

Report of Committee on Standard Time (continued).

The second letter is dated January 10th, 1896.

Mr. Chas. Warren Hunt,
Secretary.

Sir,—In my letter to you of December 31st, I referred to the adoption of Standard Time in other countries, and brought to your attention the fact that measures had been taken to carry into effect throughout the world the recommendation of the sixth resolution of the Washington International Conference of 1884. I explained that as the result of much correspondence, difficulties had been overcome, and a degree of unanimity had been reached which warranted the reasonable expectation that the recommendation of the conference would meet universal recognition. I regret to state that I have received information which destroys the hopeful view which I then expressed.

It appears that Austria, Brazil, France, Great Britain, Mexico and Spain, each of which publishes annually an astronomical ephemeris, have each consented to accept the principle of the Washington resolution and to frame their respective nautical almanacs in accordance therewith; with the understanding, however, that, as a matter of course, the United States would have adhered to the resolution and act in concert with these nations. Contrary to all expectations, the officers in charge of the nautical almanac at Washington object to the introduction of the proper change, and, as a consequence, the governments which have placed their conditional assent on record, decline to take further proceedings.

As the American Society of Civil Engineers took a leading part in initiating the movement for the reform of the notation of time and in obtaining its official recognition from the Government of the United States, it may be well to recall to the attention of the Members present at the Annual Meeting some prominent facts connected with the proceedings of the Society and with the subject itself.

At the meeting of the American Society of Civil Engineers in Washington in May, 1882, a resolution was passed directing that a petition should be presented to Congress on the subject. Consequent on this proceeding, in August following, the Senate and House of Representatives passed an Act authorizing the President of the United States to invite the Governments of all nations to appoint delegates to meet in Washington. Twenty-six nations responded to this national invitation and their delegates met in conference in Washington in 1884.

Six resolutions bearing on the question of time-reckoning were passed. The sixth was presented by the delegates appointed by the Government of the United States. Its object was to abolish, in the interests of navigation, the dual reckoning of time at sea; this proposal was received by the delegates of all the nations represented with unanimous favor, and the resolution was carried without a division.

On December 4th, 1884, the Superintendent of the United States Naval Observatory, Commodore S. R. Franklin, issued a General Order to carry out the terms of the resolution; the order was subsequently suspended with the view of giving ample time to all concerned for carrying it out. On January 9th, 1888, the President of the United States in a message to Congress further endorsed the resolutions of the Conference and recommended their formal approval by Congress.

Thus initiated and sanctioned by the people and Government of the United States, the movement to simplify and unify the reckoning of

time at sea, as on land, obtained the assent of the governments of other nations, and especially of those nations which publish nautical almanacs; of these, as I have stated, Austria, Brazil, France, Great Britain, Mexico and Spain have unequivocally signified their consent to the recommendation of the Washington Conference, and, moreover, are willing practically to carry it out by making the change simultaneously on a prearranged date, with the understanding that this course will be likewise taken by the United States.

Astronomers are agreed that astronomical time reckoning can with least disturbance be brought into harmony with civil reckoning on the day when one century passes into another,, and as nautical almanacs from 1901 have to be prepared some four years in advance, it is indispensable that there should be no delay in reaching a final decision.

The information I have received within the last few days plainly established that, under the circumstances I have named, no further steps will be taken by the nations who have conditionally accepted the recommendations of the Conference. The matter rests with the United States, and it will come to naught if the United States now withholds its acquiescence. In the event, however, of the United States acceding to the sixth resolution of the Washington Conference of 1884, provided assent be not too long delayed, the other nations will be prepared to act in concert, and the terms of the resolution will practically be carried into effect throughout the world on the first day of the twentieth century.

Should this desirable result be attained and the principle so beneficial to navigation be brought into general use, the action of the American Society of Civil Engineers will be honorably affiliated with it by the mariners of all future generations.

SANDFORD FLEMING,
Chairman of Special Committee On Standard Time.

The PRESIDENT.—Gentlemen, you have heard the informal report of the Committee on Standard Time. The subject is now before the Society. Has any one any remarks to make on this interesting and important subject?

Mr. COHEN.—The subject-matter of this report is one of very great importance, and inasmuch as the American Society of Civil Engineers has in the past taken action in regard to standard time, and I believe petitioned in regard to it, it seems to me that it is quite proper and fitting that at this moment it should take some action to prevent the loss of all that has been done in the past, which we understand from Mr. Fleming's report, and he thoroughly understands the subject from all the time he has been devoting to it, must be consummated now or must go over for a long time in the future. It seems to me, therefore, sir, quite proper that this Society should bring the matter to the attention of the President and Congress, in order that there may be a full consideration of the objections which come from so intelligent a source as that of the head of the nautical almanac. If, therefore, sir, it is in order, I would move that a communication be made to the President, perhaps in the shape of a petition; at any rate, a communication from this Society bearing on the subject, so that the matter

will have the attention at Washington which I think this Society feels that it ought to have. If in order, sir, I will offer a preamble and resolution in that regard.

The PRESIDENT.—It is in order.

Mr. COHEN.—This preamble and resolution, sir, has been framed by one of the gentlemen who has been giving the most attention to the subject, and it gives me great pleasure to offer it.

Resolution concerning Nautical Almanac.

Whereas, The American Society of Civil Engineers, in the year 1882, petitioned Congress to take measures to promote the regulation and unification of time throughout the world; and,

Whereas, Congress passed an act authorizing the President to invite the governments of all nations in diplomatic relations with the United States to appoint delegates to meet in conference in Washington to consider the subject and submit recommendations in respect thereto; and

Whereas, In response to the invitation of the President, 25 nations appointed delegates, who met delegates appointed by the United States in conference in Washington in the year 1884, and who, after a month's deliberation, passed a series of six resolutions, recommending the best course to be followed; and,

Whereas, The sixth resolution was framed in the interests of navigation, and had for its object the abolition of dual reckoning of time at sea; and *whereas*, this resolution was submitted to the conference by the delegates appointed to represent the United States, and was unanimously adopted; and,

Whereas, On December 4th, 1884, the Superintendent of the U. S. Naval Observatory issued a general order to the observatories of the United States to carry out the terms of this resolution, the execution of which general order was subsequently deferred until a general agreement among all concerned could be reached; and,

Whereas, on January 9th, 1888, the President of the United States in his message recommended that Congress should formally approve the resolutions and accept the recommendations of the International Conference; and,

Whereas, The adoption of the sixth resolution of the Conference involves the abolition of astronomical time and the substitution of civil time in nautical almanacs for purpose of navigation; and *whereas*, astronomers are agreed that astronomical time-reckoning can with least disturbance be brought into harmony with civil reckoning on the day when one century passes into another; and *whereas*, nautical almanacs for 1901 have to be prepared some four years in advance, and in consequence it is indispensable that the matter should be finally settled without delay; and,

Whereas, Austria, Brazil, France, Great Britain, Mexico and Spain, nations publishing nautical almanacs, have each unequivocally signified their assent to the terms of the resolution respecting astronomical time-reckoning, and are each prepared to frame their nautical almanacs in accordance therewith, to take effect at the beginning of the 20th century, provided the United States will do likewise and act in concert with them; and,

Whereas, Congress having taken the initiative in this reform, and the national invitation issued by the President having been accepted and acted upon, it is eminently proper and becoming that the United States should give its adhesion to the recommendations of the conference now assented to by other nations;

Wherefore, This Society respectfully petitions the President, the Senate and the House of Representatives to accept and approve the resolutions of the International Conference, which assembled in Washington in 1884, and act in concert with other nations in this matter, and cause the nautical almanac of the United States to be brought into harmony with these resolutions at the beginning of the 20th century.

The resolution was seconded.

The PRESIDENT.—The subject is before the Society for discussion. Are there any remarks? The motion made by Mr. Cohen, which follows the long preamble, reads as follows:

" *Wherefore*, This Society respectfully petitions the President, the Senate and the House of Representatives to accept and approve the resolutions of the International Conference, which assembled in Washington in 1884, and act in concert with other nations in this matter, and cause the nautical almanac of the United States to be brought into harmony with these resolutions at the beginning of the 20th century."

If there are no further remarks, the question will be put.

The question was put and the resolution was unanimously adopted.

The PRESIDENT.—The next thing in order is the report of the Committee on the Analysis of Iron and Steel. This is likewise an informal report which will be read by the Secretary.

The Secretary read the following letter:

Report of Committee on Analysis of Iron and Steel.

ALTOONA, PA., November 18th, 1895.

Mr. CHAS. WARREN HUNT,
Secretary, American Society of Civil Engineers,
127 East Twenty-third Street, New York City.

Dear Sir,—Referring to yours of November 15th.

The Sub-Committee on Methods for the Analysis of Iron and Steel are making the most strenuous exertions to have a report ready for the Annual Meeting. We had intended to have one for the midsummer meeting, but the work on the report has proven so laborious that we did not succeed, and it is barely possible that we may not succeed in getting the report ready by the 15th of December, but we will do everything possible. We are getting letters from the chemists of the country asking when the next report will be ready, and if it should not be possible to get the report out by the 15th of December, would it not be possible to have a little longer time, and also would it be possible to have the report printed and distributed interim. between the Annual Meeting and the next mid-summer meeting? I ask these questions because of the difficulty of saying positively whether a report would be formulated by December 15th. The members of the Sub-Committee are separated and most of them very busy men, and it may not be possible to get the report out by December 15th.

Very truly yours,
CHAS. B. DUDLEY,
Chairman Sub-Committee.

The PRESIDENT.—Are there any remarks to be made on the report of this Committee? If not, the next thing in order is the report of the Committee on Units of Measurement, this also being an informal report which the Secretary will read.

Mr. T. Guilford Smith.—Mr. Chairman, before passing to that report I would like to know whether it is not possible to grant that request of the Committee on Uniform Analysis. I suppose the Secretary has made no formal answer to that point to the gentleman.

The President.—It is competent for this meeting to take any action it sees fit on that report.

Mr. Smith.—The object on my part is this: Large numbers of members are looking forward to that report with very great interest, and to wait another 12 months before it appears seems a long time.

The Secretary.—It is not necessary, Mr. Smith. The Committee could present a report at any time provided it is placed in the hands of the Secretary 30 days before the next convention, and it will be sent out as suggested by the Chairman of the Committee.

The Secretary read the letter from the Chairman of the Committee on Units of Measurement, as follows:

Report of Committee on Units of Measurement.

Ithaca, N. Y., December 20th, 1895.

Chas. Warren Hunt,
Secretary, American Society of Civil Engineers.
127 East Twenty-third Street, New York.

Dear Sir,—Fearing that I may not be able to report in person at the Annual Meeting upon the work of the Committee on Units of Measurement, I beg to offer through you to the Society the following report as Chairman of said Committee:

After some preliminary correspondence the members of the Committee were all present at a meeting held in the rooms of the American Society of Civil Engineers. The questions forming the subject-matter for the investigation of the Committee were discussed at length, and a certain amount of work was distributed among the various members of the Committee. This work, however, was based upon certain inquiries that the Chairman was to make by correspondence with manufacturers, scientific societies and government bureaus, more or less likely to furnish all the data obtainable in the case, for the study of this Committee. The health of the Chairman and important professional engagements have prevented him from carrying out the intentions of the Committee as well as his own. But the Chairman has had some correspondence, and blocked out a method of attacking the question, which, although incomplete, may still be utilized for the purposes of the Committee. The Chairman had the pleasure of attending a session of the French Institute, to which body he personally applied for such aid and information as could be of advantage to the Committee. He regrets to say that the members of the Geodetic and Metrological Section under the able presidency of the Director of the Berlin Observatory seemed to look upon the information asked as an echo from the yearnings of an uncivilized people at a remotely past period of society. While the complexion of this section is made up of individuals of all nationalities, they, indeed, seemed amused at the seriousness with which I solicited their aid, and could not understand how at this period of the world's progress any one could be in doubt as to the impracticability of any other than the metric system for the scientific, industrial, commercial and politico-economic purposes of society. They, indeed, seemed to appreciate and respect the injusti-

fiable stubbornness of the English-speaking people in this regard, but evidently thought that the time had passed for investigations as to the utility of the various systems, when all the progress made by the world during the past 50 years, both in England and in America as well, had been based, and could not be based upon any other than the metric system. In the judgment of the Chairman, the incalculable loss of time and English energy wasted in reductions was simply tolerated by a racial characteristic difficult to interpret, but quite much more impossible to combat.

I may add, however, that the Chairman of the Section was kind enough to write for me a letter so properly addressed and worded as to be likely to enlist on the side of this Committee the best offices of that branch of the French Institute more likely to further our purposes.

Although the Chairman of your Committee is not able to report any substantial advance of its labors, he is anxious to report progress, and asks that the Committee be continued; and also he desires to accept, although with regret, the entire blame for the apparent lack of success of the work of the Committee. For this reason he tenders hereby the resignation of his chairmanship, and hopes that the new Chairman may be less annoyed by the ill-health and lack of time attending the efforts of the present Chairman.

The Chairman of the present Committee of Units of Measurement will hand over to his successor all the data now in the possession of the Committee, and will be at all times ready to aid him to the full extent of his ability and power, although he does not desire the official responsibilities of membership.

Very respectfully,

E. A. FUERTES,

Chairman of the Committee on Units of Measurement.

The PRESIDENT.—Gentlemen, you have heard the informal report of this Committee. The subject is now before the Society for discussion.

Mr. EDWARD P. NORTH.—Mr. President, I would move that the Committee be dismissed. (Seconded.) I do not understand, Mr. President, that it is any use to the American Society of Civil Engineers. It takes up our time, it is an impracticable study, and it is no use to any man in America or to any man who speaks English.

The PRESIDENT.—The Chair would like to suggest that if a motion of this kind is going to be passed by the Society, it had better be passed in a somewhat different form. As the Chair understands the motion of Mr. North, it is that the Committee on Units of Measurement be dismissed.

Mr. NORTH.—Perhaps it would be better to say discharged, and I would like to add – discharged with thanks.

The PRESIDENT.—If the Chair may make a suggestion, I would suggest that the informal report of the Committee be accepted as a formal report, and the Committee discharged with thanks. It appears to the Chair that that would be a more courteous way of passing the resolution.

Discussion on Report of Committee on Units of Measurement.

Mr. NORTH.—I would be very happy to have it stated in that way, sir.

Mr. PETERSON.—I have much pleasure in seconding that.

Mr. ROBERT CARTWRIGHT.—According to Mr. North's motion, it is a reflection on the Committee, as I deem it. I was about to propose that the request of the Chairman be considered, and that Mr. North be appointed to fill the place.

The PRESIDENT.—Do you make that as an amendment to Mr. North's motion?

Mr. CARTWRIGHT.—If Mr. North will accept that as an amendment, I certainly shall.

The PRESIDENT.—Does Mr. North so accept it?

Mr. NORTH.—I do not think it is proper for a man to take the chairmanship of a committee, the work of which he is opposed to.

The PRESIDENT.—I understand you do not accept it?

Mr. NORTH.—No, sir.

The PRESIDENT.—As the amendment is not seconded and is not accepted by the maker of the motion to which it is an amendment, it falls. Are there any further remarks on Mr. North's motion?

Mr. COHEN.—It seems to me before we take any action looking to such a summary disposition of this Committee and the work that it has been charged with, it might be well if the Society were informed as to precisely what the functions of the Committee were. Could we have the resolution read under which that Committee was appointed, and the method of its appointment? I know it was some years ago, and if we could be refreshed just a little as to what was done in that regard, we would be better able to conclude as to final disposition.

The PRESIDENT.—Is any member of this Committee present?

A MEMBER.—Mr. President, can you give us the names of the members of the Committee?

The PRESIDENT.—E. A. Fuertes, George M. Bond, William M. Black, R. E. McMath, George F. Swain.

The PRESIDENT.—It will take some time to find the original resolution. It can be found, however. It will probably take a half an hour or more to get it. The Committee is appointed under the provisions of Section 13 of Article 6 of the Constitution, providing for the appointment of special committees—"A majority of a total vote of not less than one-third of the Corporate Membership of the Society shall be necessary for its adoption" (that is, to the adoption of a resolution for the appointment of a special committee). "Whereupon the committee so authorized shall be appointed by the Board of Direction." Other committees of this kind have been appointed, and, on submitting their final report, have been discharged by the Society.

Mr. COHEN.—It appears to me that action upon this report might be deferred to a later moment of this Business Meeting of the Society,

and in the meanwhile some little information given as to the history of the appointment of this Committee and the precise function with which it was charged at the outstart. I believe it has been in existence for a number of years. There was some difficulty, I believe, in getting men to work upon it at the start. There are some strong names there now, and it seems to me due to the gentlemen who have accepted positions on that Committee that they should not be cleared out in quite so summary a manner. Let the Society, with whom the whole question lies, be well informed as to what they charged these gentlemen to do.

Mr. KNAP.—I am opposed to Mr. North's motion, for the reason that the Chairman of the Committee recommends that the Committee be continued. He has given us a good report, and no matter what the future of it may be, I think we ought to continue the Committee at least another year.

Prof. PALMER C. RICKETTS.– I would simply like to ask if it is not possible that Prof. Fuertes in his letter has not used those sarcastic remarks of the Royal Astronomical Observatory of Berlin to indicate that possibly it would be well to withdraw that Committee rather than to have this country spoken of again as a set of barbarians; whether he does not mean to provide an easy way for the Society to get out of the difficulty. That is the way the letter appeared to me—that possibly that interpretation might be put upon the Professor's letter. I have no reason to suppose this except from the contents of the letter.

Mr. KNAP.—One portion of the report which seems to be in earnest is that one wherein he recommends the continuance of the Committee.

The PRESIDENT.—The Chair would state that Prof. Fuertes sent to me his resignation, to take effect at an earlier date, and on my request he postponed it until the time of the Annual Meeting. I think there is no doubt that Prof. Fuertes is interested in the subject, and hopes that the Committee will be continued.

Mr. JOHN THOMSON.—I would offer an amendment to Mr. North's resolution—that this Committee be continued with the request, or the instruction (if that is proper) of this meeting that it place before the Society a final report in time to be acted upon at the next Convention.

The motion was seconded by Mr. Cartwright.

The PRESIDENT.—Mr. Thomson's amendment to Mr. North's motion is accepted by Mr. North. The motion as it now stands is, that the informal report of the Committee be accepted as a progress report, and that the Committee be continued and requested to submit a final report at the next Annual Convention. Are there any remarks to be made on this motion as now before the house?

A MEMBER.—Would that prevent the acceptance of Prof. Fuertes' resignation?

Report of Committee on Units of Measurement accepted and Committee continued.

The PRESIDENT.—The Chairman would rule that the acceptance of Prof. Fuertes' resignation is a matter for the Board of Direction to act on, he having been appointed by the Board.

Mr. Thomson's motion was then put and carried.

The PRESIDENT.—Gentlemen, there are no other reports to be made, and the meeting is open now for any business which any Member wishes to introduce.

Discussion on Committee on Uniform Methods of Testing Structural Material.

Prof. WILLIAM H. BURR.—A year ago the Committee on Uniform Methods for Testing Structural Material made its report. I am not aware whether the report was accepted or not, although I do know that it led to considerable discussion. But the Committee was never discharged, and I would like to move now that the Committee be discharged. (Seconded.)

The PRESIDENT.—Gentlemen, the motion is that the Committee on Uniform Methods of Testing Structural Material be discharged. This motion is made by Prof. Burr, who was Chairman of the Committee. The Committee was considered as discharged in the past year, no mention being made of it in the list of Committees in the *Transactions*. The motion calls for a formal act, which has not yet been had. Are there any remarks ?

Mr. SMITH.—I was present at the Annual Meeting a year ago and there was a *quasi* report presented. I remember distinctly that the Committee was not formally discharged. I would like to have Prof. Burr as the Chairman of the Committee state what ground he has for asking for the discharge of so important a committee. The reasons which were originally given for the appointment of such a committee seem to me to still hold good. The Society has certainly done itself great credit already by its action on uniform sections of rails, and I suppose it will do the same in reference to methods of analysis of ores, and I do not see why such a committee is not a perfectly proper and competent one for this Society. I would be very glad if Prof. Burr would give us the reasons for asking the discharge of so important a committee.

Prof. BURR.—I would like to say that if the reasons for asking for the discharge of the Committee were stated in full I am afraid it would occupy the entire time of this meeting and somewhat more. I would only say briefly, that if I understand the sentiment of the majority and perhaps of every member of the Committee, it is simply this—that it has accomplished, whether that be much or little, as much as it can perform advantageously to the Society or within the reasonable limits of its own efforts. It is a subject which requires, if it is to be treated in full, far more time than I for one of the Committee, at least, can give to it. When it was realized by the Committee that the magnitude of the work was considerably more than probably the Members of the Society contemplated, it was considered best to

round up its operations in the most concise manner that could consistently be done. It appeared, however, that the views of the Committee were not exactly those of at least some Members of the Society. But I think that I am only making a fair statement of the views of the Committee when I say that they considered, at least, that they had accomplished, when the report was made a year ago, about all that they could do, and consequently they concluded to make their report as a final report, and it is for that reason that I have made the motion which has just been seconded. If the Committee is to be continued, which of course is within the province of the Society to decide, I think that at least one or two of the members will have to be appointed, but that is not germane to the motion. The reasons for my motion are those which I have just given briefly. They might be considerably extended.

Mr. Smith.—I did not understand that the Committee is to be abolished by this resolution of Prof. Burr's.

The President.—The resolution as made by Prof. Burr discharges the Committee. That would be the end of the Committee's doings.

Mr. Smith.—It only discharges those members, does it not? The Committee is continued with new appointments. Is not that the idea?

The President.—That is not the idea as understood by the Chair. The Committee was appointed for a particular purpose. The Committee says it has performed its duty so far as it is able and requests its discharge. A new Committee can be appointed for the same purpose, but the Chair would rule that this would discharge that Committee.

Mr. Smith.—Then I hope very much that the motion will not prevail. There is nothing that has done to bring the Society so much into harmony with the manufacturers of steel rails as the report on rail sections, and this appears to me to be an identical case. It is quite true that since the report of a year ago a large number of steel manufacturers have got together and adopted standard specifications for steel. But that is not exactly germane to the subject of investigation by this Committee, and I hope very much that the Society will not adopt the motion.

Committee on Uniform Methods of Testing Structural Material discharged.

The President.—The motion before the house is that the report made last year by the Committee on Uniform Methods of Testing Materials used in Metallic Structures and the Requirements of Those Materials to Further Improve the Grade of Such Structures be accepted as their final report and the Committee discharged.

The motion was carried.

Mr. Smith.—Is it proper, Mr. President, to ask for a committee on that same subject?

The President.—Such a committee will have to be appointed in accordance with the provision of Section 13 of Article 6 of the Constitution. (The President read the section.)

Mr. SMITH.—Then may I ask if this Committee that has just been discharged has gone through all this process to arrive at this very painful result ?

The PRESIDENT.—Yes, sir ; it has. Is there any other business to come before this meeting ?

Mr. G. LEVERICH.—Mr. President, I have a resolution to offer which the Secretary will kindly read.

The Secretary read the following resolution :

Resolution concerning Acceptance of Transportation and other Favors at Conventions.

Resolved, That the majority of Members present at this Annual Meeting, first, express disapproval of the acceptance at the Annual Convention of transportation, hospitality or favors extended by corporations or by persons not connected with the American Society of Civil Engineers, or by Members resident at the place where the Convention is held involving expense to them or to others ; and second, that the Board of Direction, when arranging for future Annual Conventions, give full weight to this expression of opinion.

Mr. LEVERICH.—Mr. President, I propose to submit this without debate.

The PRESIDENT.—As I understand it the mover of this resolution has no remarks to make. Do I further understand that it is the wish here that a vote shall be taken without any remarks by anybody ? It is not within the rules and cannot be done except with the consent of the Members present.

Mr. LEVERICH.—I will explain, Mr. President, that I wish to present this simply upon its merits without any particular argument. I will, however, quote what was printed in the daily journals yesterday as being a remark by a prominent city official; he said he had found a new proverb: "Pay as you go, and if you can't pay, don't go."

Mr. FOSTER CROWELL.—I am sorry that the gentleman who offers the resolution has not explained in detail exactly what he means. But I wish to oppose very thoroughly all that it implies. As far as I know —and I am probably as guilty as any other person of getting facilities for the use of the Society, which are not provided by the Members of the Society themselves—as far as I know, the facilities which of late years have been granted to the Society have been given in a way that does not commit the Society, or, what is still more important, any individual Member of the Society, in accepting such hospitality and such facilities, which have been in the form of equal hospitalities to all the Members of the Society who might happen to be present at a convention. There are, of course, other ways in which the Society might receive hospitality. But in this way it does not commit anyone and the advantage to the Society has been very strongly demonstrated on two occasions. The two occasions I refer to are the Niagara Falls Convention and the Convention last year at the Hotel Pemberton, which were the most successful Conventions which the Society has held in its history, the last one being more successful than the one

before. A very large portion, I think, of that success was due to the fact that facilities were furnished to this Society in such a way that it made it easy for the Members to reach places, and without those facilities they could not have done so. It is not only a question of money——

The PRESIDENT.—Mr. Crowell, if you will excuse me, it is now 12 o'clock, the time for closing the ballot for the election of officers. Has every gentleman voted ? If not, an opportunity is now given to vote. I declare the polls closed.

Mr. CROWELL.—I have said all that I think is necessary to say. I hope that this resolution will not prevail.

Mr. COHEN.—I have one word to say on that subject, sir. I feel very sure that facilities granted to the American Society of Civil Engineers by railway corporations and others, which no doubt are granted by them with pleasure, may be received by the Society in the same way. It adds greatly to the convenience and the comfort of the Society, and I think may always be accepted without any feeling of individual obligation and only a proper feeling of corporate acknowledgment and thanks. When it comes to gentlemen in a locality which has been determined on for the visit of the Society having to go around making collections for the entertainment of this Society, I think that may be considered in a different way. I, myself, feel, under such circumstances, that we would rather not have that sort of thing done, and I imagine it is that to which the resolution of Mr. Leverich refers and not perhaps to such courtesies as are extended by railway corporations and others. I have myself felt that we were under peculiar obligations when gentlemen have to make large collections to entertain us in a way that we are able to entertain ourselves if we desire it. Therefore, if there can be any division of that resolution, an amendment to it so as to make it cover that part of it that I recognize, I should be glad to vote for it ; otherwise not.

The PRESIDENT.—Mr. Cohen, do I understand that you have an amendment to make to this motion ?

Mr. COHEN.—No, sir.

Mr. LEVERICH.—Mr. President, if we are now approaching the end of the debate I would say that I purposely withheld any statement I might wish to make to the Members of the American Society of Civil Engineers representing, in my judgment, the grandest profession practiced by men, who do not in any sense accept gratuities from anybody, able themselves to do and perform for themselves and others what they undertake, and proving their ability by the fact that they are in positions where they so do. I have known instances in my official relations with this Society where Junior Members have been called upon to pay sums for entertainment at conventions, which they met with the spirit which a Junior should show, from their own personal purse. I have known of

Discussion on Resolution concerning Acceptance of Transportation and other Favors at Conventions.

instances where a single contractor has offered to pay the whole bill. This resolution was carefully prepared. If there is any gentleman, Member of the Society, who individually or as connected with corporations shall be desirous of tendering hospitalities to the Society, this resolution does not in any sense prevent that, and I presume that we could all gratefully accept such. Years ago, in my juniorship, riding with a contractor on a street car and proposing to pay my fare, he said, "No; no engineer pays anything when there is a contractor on board." Are we not able to pay our way? Is this profession in such a condition that we are going to accept gratuities? Not at all. Again, very largely because of the generous hospitalities of the men who have entertained us, we have made our conventions what? Junkets. A large number of us have absented ourselves from the discussions which were pertinent to us as a body, and to our profession, and we have gone riding or boating. I leave the question with you, gentlemen.

Mr. Charles Sooysmith.—It strikes me that this motion carried in the shape in which it is put might seriously embarrass the Board of Direction in making such arrangements as may be necessary for the Convention, especially with reference to transportation. I would say, in general, too, that it seems to me that the Board would be very mindful of what is due to the Society in accepting favors, and that they can be trusted not to accept favors that would not be agreeable to the Society. Therefore, I am opposed to the resolution. I would move an amendment, that, if passed, it be with the acceptance of such arrangements as the Directors see fit to accept.

Mr. George R. Hardy.—It seems to me that a resolution passed at this time in the way in which this is suggested would be somewhat a reflection upon the action of those individuals and corporations who have so kindly assisted at the past conventions. I am not sure that it would be considered in any other way, and as a Member who is connected with one of those corporations I sincerely hope that the resolutions as suggested will not be acted upon by the Society, but that the matter be referred to the Board of Direction.

Mr. Smith.—Was Mr. Leverich's motion seconded?

The President.—Mr. Leverich's motion was seconded. Mr. Sooysmith's motion was not seconded.

Mr. William L. Saunders.—I move that the motion by Mr. Leverich be tabled. (Seconded.)

A Member.—Does that refer to the original resolution?

The President.—The only resolution before the house is the original resolution of Mr. Leverich, and it is now moved that that be laid upon the table.

Resolution concerning Acceptance of Favors tabled.

The motion to lay on the table was put and carried.

The President.—A motion would now be in order on the line of the amendment that the Board of Direction be requested to consider the matter embraced in this resolution.

Mr. Sooysmith.—I would simply suggest that it is a reflection on the Board of Direction to instruct them to consider such matters.

The Secretary.—I will again read the programme for the benefit of those who have come in late. Invitations to visit Places of Interest read.

The President read the following letter:

Sprague Electric Elevator Company,
Postal Telegraph Building,

New York, January 14th, 1896.

George S. Morison, Esq.,
President, American Society of Civil Engineers,
Cor. Twenty-third St. and Lexington Ave., N. Y.

Dear Sir,—I regret that you cannot visit my factory Thursday afternoon. I understand, however, that Friday morning will be convenient to your Members. I shall be very glad, then, to have such as wish come Friday morning. The most convenient train leaves the foot of Barclay or Christopher Streets at 9.20 in the morning. Trains return every 40 minutes.

In addition, I shall be glad to have such of the Members as may wish visit the elevator plant in this building any time Thursday afternoon. I hope that some of the Members will take advantage of this opportunity.

Very truly yours,
F. J. Sprague.

Mr. George E. Gifford.—Col. Walter Katté, Chief Engineer New York Central and Hudson River Railroad Company, and The King Bridge Company, will be glad to show such of the Members of the Society as may be interested the work now in progress on the Park Avenue improvement and draw-bridge and approach spans over the Harlem River at Fourth Avenue to-morrow afternoon (Thursday) after lunch at the Society House.

Mr. Gifford, of The King Bridge Company, will be present at the lunch, and the start will be made immediately thereafter. On account of the shortness of the daylight hours, the start from the Grand Central Station should be made not later than the 3.09 train (Harlem Division).

The President called the attention of the Members to a design for the New House as prepared by Mr. Wilson.

Mr. Woodbury read the report of the tellers.* Report of Tellers read.

The President.—In accordance with the provisions of the Constitution, I declare that Mr. Thomas Curtis Clarke is elected President of the American Society of Civil Engineers, and Mr. William Rich Hutton, of New York City, and Mr. Peter Alexander Peterson, of Montreal, are elected Vice-Presidents of the American Society of Civil Engineers. That Mr. John Thomson, of New York City, is elected Treasurer of the American Society of Civil Engineers. That Mr. George Alexander Just, of New York City; Mr. William Barclay Parsons, of New York City; Mr. Horace See, of New York City; Mr. John Ripley Freeman, of Boston, Mass.; Mr. Daniel Bontecou, of Kansas, City, Mo., and Captain Thomas William Symons, of Portland, Ore., Announcement of Officers for 1896.

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are elected Directors of the American Society of Civil Engineers. As the President-elect of the Society is in the room, if he would come forward I think the whole Society would be glad to hear from him.

Mr. Clarke, President, introduced.

It affords me great pleasure to introduce to you one who requires no introduction whatever, Mr. Thomas Curtis Clarke, President of the American Society of Civil Engineers. (Applause.)

President CLARKE.—Gentlemen, I have to thank you most heartily for the expression of confidence which you have made in electing me to the honorable office of President. The chair is not a bed of roses, as my friend Mr. Morison can tell you. It is an office which requires hard work; but I have always been accustomed to hard work, and I shall continue that practice during the time that I am President. I have heard or read somewhere that there are two epochs in a man's life, one when he is discovered and the other when he is found out. You have discovered me to-day, and I hope that when the time comes when I shall join that ancient and honorable body, the Past-Presidents of this Society, that you will say, "he did as well as he could." (Applause.)

Mr. GEORGE S. MORISON.—The President spoke truly when he said there is plenty of work for the President to do. I have no doubt that when he has fulfilled his promise of doing as well as he can that we shall find that his capabilities are very great. Gentlemen, is there any other business to come before this meeting? If there is no other business, a motion to adjourn is in order.

Mr. KNAP.—I wish to move a vote of thanks to the late President for the admirable manner in which he has filled the chair. (Seconded.)

The motion was put by Mr. Knap and carried.

Mr. MORISON.—The late President certainly feels very much gratified that his labors have been thought so well of. It has been his endeavor to do what he could and he is very glad if the Society feels that he has succeeded.

Final Adjournment of Annual Meeting.

Adjourned.

Wednesday Evening, 20 o'clock.—An address illustrated by lantern slides was delivered by H. W. York, Jun. Am. Soc. C. E., on "The Central Station of the United Electric Light and Power Company."

Thursday, January 16th, 1896.—At 9.30 o'clock a special train on the Delaware, Lackawanna and Western Railroad conveyed about 170 Members and guests to the works of the Crocker-Wheeler Electric Company, S. S. Wheeler, M. Am. Soc. C. E., President, at Ampere, N. J. After an inspection of this interesting plant, the party returned to the Society House, where at 13.30 o'clock luncheon was served.

During the afternoon excursions were made by special invitation of the engineers in charge to the Brooklyn Bridge, the central station of the United Electric Light and Power Company, and the new bridge of

the New York Central and Hudson River Railroad Company over the Harlem River.

At 20 o'clock a reception and conversazione was held at Delmonico's, which was attended by 212 Members and ladies.

The Members of various grades in attendance at the Annual Meeting and excursions were as follows:

C. H. Allen..........New York City.
F. J. Amweg.......Philadelphia, Pa.
William Aycrigg .....New York City.

John W. Bacon......Danbury, Conn.
William Henry Baldwin,
Yonkers, N. Y.
William J. Baldwin...New York City.
Charles J. Bates....Englewood, N. J.
George Baum........New York City.
Arthur Beardsley ..Swarthmore, Pa.
W. E. Belknap......Brooklyn, N. Y.
John A. Bensel. .....New York City.
George H. Benzenberg,
Milwaukee, Wis.
George H. Bishop,
Middletown, Conn.
H. Bissell......West Medford, Mass.
F. W. Blackford........Butte, Mont.
John Bogart.........New York City.
Alfred P. Boller......New York City.
Charles P. Bonnett...Elizabeth, N. J.
Louis B. Bonnett ...Elizabeth, N. J.
G. W. Bramwell .....New York City.
W. H. Breithaupt ...New York City.
J. Breuchaud........ Yonkers, N. Y.
Waldo C. Briggs,
South Norwalk, Conn.
Charles B. Brush. ...New York City.
L. L. Buck..........New York City.
William H. Burr. .. New York City.

Albert Carr.... East Orange, N. J.
Robert Cartwright...Rochester, N. Y.
George W. Catt ......New York City.
Edward J. Chibas..Colon, Colombia.
S. H. Chittenden....East River, Conn.
G. L. Christian.......Yonkers, N. Y.
B. S. Church.......New York City.
L. V. Clark, Jr.....Philadelphia, Pa.
Thomas C. Clarke....New York City.
Freeman C. Coffin......Boston, Mass.
T. Amory Coffin.....Phœnixville, Pa.
William B. Cogswell..Syracuse, N. Y.
Mendes Cohen........Baltimore, Md.
Howard J. Cole......New York City.
Francis Collingwood..Elizabeth, N. J.
Silas G. Comfort........Chester, Pa.
Alfred G. Compton...New York City.
S. L. Cooper... .....Yonkers, N. Y.
Theodore Cooper ....New York City.
William P. Craighill,
Washington, D. C.
Albert S. Crane .... Brooklyn, N. Y.
R. Walter Creuzbaur,
Gautemala City, Gautemala.
J James R. Croes....New York City.
Horace Crosby. New Rochelle, N. Y.
Foster Crowell.......New York City.

Charles G. Darrach..Philadelphia, Pa.
J. V. Davies..........New York City.
Arthur L. Davis...... St. Albans, Vt.
Joseph P. Davis... . New York City.
John Sterling Deans. Phœnixville, Pa.
Edward W. Dewey .. New York City.
S. L. F Deyo.........New York City.
Emil Diebitsch......Brooklyn, N. Y.
R. D. Dodge........Brooklyn, N. Y.
Albert B. Drake..New Bedford, Mass.

J. H. Edwards ...East Berlin, Conn.
J. W. Ellis ....Woonsocket, R. I.
C. C. Elwell.........Norwich, Conn.
Charles E. Emery.....New York City

John F. Fairchild..Mt. Vernon, N. Y.
J. A. Fairleigh......Brooklyn, N. Y.

J. M. Farley.....White Plains, N. Y.
H. H. Farnum.......New York City.
John W. Ferguson... Paterson, N. J.
W. H. Ford ....Hanover, N. H.
Charles Francis.......Davenport, Ia.
E. G. Freeman......Brooklyn, N. Y.
John R. Freeman .....Boston, Mass.
Alexis H. French....Brookline, Mass.
James B. French.....Richmond, Va.
George H. Frost.....New York City.
A. Fteley ....New York City
Frank L. Fuller........Boston, Mass.

F. Lynwood Garrison,
Philadelphia, Pa.
Charles W. Gay.........Lynn, Mass.
Martin Gay..West New Brighton, N.Y.
George Gibbs ......Milwaukee, Wis.
George E. Gifford....New York City.
Robert Giles ....Athens, Pa.
Henry H. Gladding,
New Haven, Conn.
Henry Goldmark ....Chicago, Ill.
John M. Goodell.....Brooklyn, N. Y.
E. Sherman Gould...Yonkers, N. Y.
Edwin D. Graves, Middletown, Conn.
Samuel M. Gray....Providence, R. I.
William Gray..........Carmel, N. Y.
George S. Greene, Jr. New York City.

S. S. Haight ....New York City.
Caspar W. Haines..Philadelphia, Pa.
Charles Hansel ....Easton, Pa.
George E. Harding....New York City.
George R. Hardy....Stamford, Conn.
Charles M. Harris....New York City.
Robert L. Harris.....New York City.
B. M. Harrod......New Orleans, La.
William J. Haskins...New York City.
C. W. Hazleton,
Turners Falls, Mass.
D. W. Hemming.....New York City.
Rudolph Hering.....New York City.
Clemens Herschel....New York City.
S. W. Hoag, Jr...... New York City.
Frank W. Hodgdon....Boston, Mass.
Henry W. Hodge.... New York City.
Theo. G. Hoech,
Washington, D. C.

T. O. Horton.........New York City.
J. T. N. Hoyt........New York City.
Alfred E. Hunt......Pittsburgh, Pa.
Charles Warren Hunt. New York City.
J. B. Hurtig ....New York City.
William R. Hutton...New York City.

A. Langstaff Johnston,
Richmond, Va.
George A. Just ......New York City.

William D. Kelley....New York City.
Cassius W. Kelly..New Haven, Conn.
R. Khuen ....Pencoyd, Pa.
George A. Kimball.....Boston, Mass.
C. C. King. West New Brighton, N. Y.
Paul S. King........Waltham, Mass.
Joseph M. Knap.....New York City.
Walter H. Knight... New York City.

Eugène Lentilhon....New York City.
H. R. Leonard ...Philadelphia, Pa.
Robert W. Lesley..Philadelphia, Pa.
G. Leverich........Brooklyn, N. Y.
M. Lewinson........New York City.
Nelson P. Lewis.....Brooklyn, N. Y.
H. J. Lindsay........Pittsburgh, Pa.
F. B. Locke............Boston, Mass.
Thomas J. Long......New York City.
Thomas D. Lovett..Cincinnati, Ohio.
Oscar Lowinson .....New York City.

Charles Macdonald...New York City.
William W. Maclay,
Glens Falls, N. Y.
James MacNaughton...Albany, N. Y.
C. C. Martin ....Brooklyn, N. Y.
Kingsley L. Martin..Brooklyn, N. Y.
De Courcy May .....Baltimore, Md.
Joseph Mayer........New York City.
James C. McGuire..Ellicott City, Md.
T. H. McKenzie.....Hartford, Conn.
Alex. Rice McKim....New York City.
T. J. McMinn........New York City.
D. N. Melvin....Linoleumville, N. Y.
A. G. Menocal......Brooklyn, N. Y.
Mansfield Merriman,
South Bethlehem, Pa.
Henry C. Meyer .....New York City.

Edwin Mitchell......Manchester, Va.
Daniel E. Moran.....New York City.
George S. Morison.. ...Chicago, Ill.
Mace Moulton......Springfield, Mass.
Charles H. Myers....Brooklyn, N. Y.

Robert E. Neumeyer..Bethlehem, Pa.
O. F. Nichols........Brooklyn, N. Y.
Edward P. North ....New York City.
Albert F. Noyes.......Boston, Mass.

F. S. Odell ....Mt. Vernon, N. Y.
E. E. Olcott..........New York City.
L. F. Olney...... ..Mahwah, N. J.
Stacy B. Opdyke, Jr.,
Philadelphia, Pa.
John F. O'Rourke ...New York City.
James Owen. ....Newark, N. J.

W. Barclay Parsons..New York City.
George H. Pegram......Omaha, Neb.
P. Alex. Peterson..Montreal, Canada.
George W. Plympton,
Brooklyn, N. Y.
John M. Porter..........Easton, Pa.
Alexander Potter....New York City.
W. A. Pratt ....Philadelphia, Pa.
Henry G. Prout......New York City.

William G. Raymond.....Troy, N. Y.
W. Boardman Reed..New York City.
Clifford Richardson ..New York City.
Palmer C. Ricketts......Troy, N. Y.
Robert Ridgway..Kingsbridge, N. Y.
Nathaniel Roberts,
Jersey City Heights, N. J.
Percival Roberts, Jr.,
Philadelphia, Pa.
William Roberts..... Waltham, Mass.
J. C. L. Rogge.......New York City.
Thomas F. Rowland..New York City.

W. L. Saunders......New York City.
A. C. Savage ....Brooklyn, N. Y.
C. C. Schneider ....Pencoyd, Pa.
Henry B. Seaman ...New York City.
Alfred F. Sears......Brooklyn, N. Y.
Horace See...........New York City.
W. W. Seitzinger.......Reading, Pa.
Ira A. Shaler.........New York City.
M. R. Sherrerd........Newark, N. J.
Frank W. Skinner....New York City.
Eugene R. Smith ....Islip, N. Y.
J. Waldo Smith .....Montclair, N. J.
Merritt H. Smith. ...Yonkers, N. Y.
T. Guilford Smith.....Buffalo, N. Y.
Nelson Fitch Smith..New York City.
Charles Sooysmith...New York City.
E. G. Spilsbury. .....Trenton, N. J.
H. R. Stanford.......New York City.
D. McN. Stauffer.....New York City.
Frederic P. Stearns....Boston, Mass.
John M. Stewart.....New York City.
Waterman Stone . Providence, R. I.
E. C. Stout. .... New York City.
A. A. Stuart........Brooklyn, N. Y.

George A. Taber.....New York City.
Lucien A. Taylor......Boston, Mass.
S. C. Thompson......New York City.
George H. Thomson..New York City.
John Thomson.......New York City.
T. Kennard Thomson,
Stamford, Conn.
George Curtis Tingley,
Providence, R. I.
A. T. Tomlinson........Chicago, Ill.
Calvin Tomkins .....New York City.
G. M. Tompson ....Wakefield, Mass.
E. E. R. Tratman....New York City.
John C. Trautwine, Jr.,
Philadelphia, Pa.
L. L. Tribus.........New York City.
W. Gustav Triest.....New York City.
Alfred W. Trotter....New York City.
E. K. Turner...........Boston, Mass.
Gustave R Tuska....New York City.
A. Harvey Tyson ....Freehold, N. J.

John D Van Buren.Newburgh, N. Y.
John G. Van Horne..New York City.
E. B. Van Winkle....New York City.
G. H. Vedeler........New York City.
Maurice A. Viele .....Katonah, N. Y.
José R. Villalon .....New York City.
C. B. Vorce.........Stamford, Conn.

Montgomery Waddell, New York City.
Guy B. Waite.... ...Hoboken, N. J.
Clement I. Walker...New York City.
Charles D. Ward.....New York City.
R. Willard Ware. ...Plainfield, N. J.
W. De H. Washington, New York City.
F. W. Watkins ....Carmel, N. Y.
Albert L. Webster....New York City.
J. A. Wells..........New York City.
S. S. Wheeler........New York City.
Frank O. Whitney.....Boston, Mass.
William H. Wiley... New York City.
J. K. Wilkes....New Rochelle, N. Y.
C. W. S. Wilson....Worcester, Mass.
Joseph M. Wilson..Philadelphia, Pa.
C. J. H. Woodbury....Boston, Mass.
William E. Worthen..New York City.

Preston K. Yates.....New York City.
Henry W. York .....New York City.

Total number of Members in all grades, 253.

MINUTES OF MEETINGS.

OF THE SOCIETY.

February 5th, 1896.—The meeting was called to order at 20.15 o'clock, President Thomas Curtis Clarke in the chair; Charles Warren Hunt, Secretary, and present, also, 65 Members and 17 guests.

Minutes of the meetings of January 8th and 15th, 1896, were adopted as printed in *Proceedings* for January, 1896.

A paper entitled "Flow of Water in 48-In. Pipes" was presented by Desmond FitzGerald, M. Am. Soc. C. E., and illustrated by lantern slides. The paper was discussed orally by E. Sherman Gould, M. Am. Soc. C. E., and the author, and a written communication from Rudolph Hering, M. Am. Soc. C. E., was read by T. J. McMinn, M. Am. Soc. C. E.

Ballots were canvassed, and the following candidates were declared elected:

As Members.

Walter Gilman Berg, New York City.
William Maxwell Brown, Jr., Boston, Mass.
William Thruston Manning, Baltimore, Md.
Edwin Harrison McHenry, St. Paul, Minn.
Forrest Milton Towl, New York City.

As Associate Members.

Jacob Louis Bauer, Elizabeth, N. J.
Herbert Thomas Grantham, Philadelphia, Pa.
Wellington Barnes Lee, Hillburn, N. Y.
Clifford Neville Miller, Covington, Ky.
Liberty Gilbert Montony, Cleveland, O.

The Secretary announced the election by the Board of Direction on February 4th, 1896, of the following candidates:

As Associate.

Charles Frederick Quincy, Chicago, Ill.

As Juniors.

William Henry Adey, Swarthmore, Pa.
Louis Jacob Affelder, Allegheny City, Pa.
Morton Burden, Pencoyd, Pa.
George Conrad Diehl, Syracuse, N. Y.
Francis Cushing Green, New York City.
Vernon Hill Gridley, Brooklyn, N. Y.
Edwin Henry Messiter, New York City.
Harry Kent Seltzer, Sioux City, Ia.
Walter Tenny Smith, Chicago, Ill.

The Secretary announced the deaths of the following Members:

Thomas Prosser, elected Fellow June 1st, 1870; died January 6th, 1896.

John A. Wilson, elected Member June 7th, 1876; died January 19, 1896.

The Secretary announced that the discussion on Mr. FitzGerald's paper entitled "Flow of Water in 48-In. Pipes" will be closed on March 15th, 1896.

Adjourned.

Wednesday, February 19th, 1896.—The meeting was called to order at 20.15 o'clock, Charles Macdonald in the chair; Charles Warren Hunt, Secretary, and present, also, 41 Members and 11 guests.

A paper by H. St. L. Coppée, M. Am. Soc. C. E., entitled "Bank Revetment on the Lower Mississippi" was presented in abstract by the Secretary, who also read correspondence on the subject from Messrs. Alfred Noble, D. M. Currie, E. E. Russell Tratman and W. G. Price.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

January 15th, 1896.—Seventeen Members present.

Standing committees were appointed as follows :

Finance Committee.—Joseph M. Knap, Chairman ; Horace See, William Barclay Parsons, F. S. Curtis, and John R. Freeman.

Library Committee.—T. Guilford Smith, Chairman ; Robert B. Stanton, A. Mordecai, Daniel Bontecou, Charles Warren Hunt.

Publication Committee.—William H. Burr, Chairman ; John Thomson, Robert Cartwright, Desmond FitzGerald, H. D. Whitcomb.

Other special committees of the Board were appointed.

Adjourned to February 4th, 1896.

February 4th, 1896.—Nine Members present.

The President announced that Charles Warren Hunt, having received the votes of 38 members of the Board for that office, was duly elected Secretary of the Society.

John M. Goodell, Assoc. Am. Soc. C. E., was appointed Assistant Secretary.

Resignations from the following Members were presented and accepted :

Levi W. Post, M. Am. Soc. C. E.
A. J. Swift, M. Am. Soc. C. E.
James Moylan, M. Am. Soc. C. E.

The matter of the new Society House was considered and other routine business transacted. Applications were considered. One candidate was elected as Associate and nine as Juniors.

Adjourned.

ANNOUNCEMENTS.

Wednesday, March 4th, 1896, at 20 o'clock, a regular meeting of the Society will be held, at which a paper will be presented by Leopold Eidlitz, Esq., entitled "The Strength of Pillars.—An Analysis." This paper is printed in this number of *Proceedings.*

Wednesday, March 18th, 1896, at 20 o'clock, a regular meeting of the Society will be held. The paper to be presented is by H. W. York, Jun. Am. Soc. C. E., and is entitled "The Twenty-eighth Street Central Station of the United Electric Light and Power Company." It is printed in this number of *Proceedings.*

Correspondence on the above papers is invited from those who cannot be present at the meetings, and may be sent by mail to the Secretary. The papers with discussion in full will be published in *Transactions.*

Discussion on the paper by Desmond FitzGerald, M. Am. Soc. C. E., entitled "Flow of Water in 48-In. Pipes," which was printed in *Proceedings* for January, 1896, will close March 15th, 1896. Discussion on the paper by H. St. L. Coppée, M. Am. Soc. C. E., entitled "Bank Revetment on the Lower Mississippi," and printed in the same number of *Proceedings*, will close April 1st, 1896.

NEW SOCIETY HOUSE.

The following subscriptions to the New Society House Fund have been received in addition to those published in *Proceedings* for January, 1896:

Arentz, F. C. H	$5	Hill, W. R	$100
Baehr, W. A	20	Johnston, J. P	5
Balbin, E. J	5	Kirkman, M. M	100
Chamberlain, P. W	50	Savage, H. N	25
Connor, E. H	20	See, Horace	100
Frizell, J. P.	100	Tratman, E. E. R	10
Fuller, F. L.	25	Vanderlip, H. E.	10
Gerber, E	25	Webster, A. L.	25
Greene, Chas. E.	20	Ziffer, E. A	5

The total amount subscribed up to February 17th, 1896, is $17 390, of which sum $13 615 has already been paid.

In the matter of a design for the New Society House, it has been decided to institute a competition in which all architects connected with the Society may participate. A limited number of architects not connected with the Society will also be specially invited to compete. The conditions of the competition will be sent to any Member who may so request upon application to the Secretary.

MEMOIR OF DECEASED MEMBER.

WILLARD SMITH POPE, M. Am. Soc. C. E.*

DIED OCTOBER 10TH, 1895.

Willard Smith Pope was born on January 16th, 1832, in the then village of Rome, N. Y. He was the son of Dr. G. W. Pope, a physician and a man of standing in the community. His early life was spent in Rome, where he attended school and prepared for college.

* Memoir prepared by George S. Morison, Past-President Am. Soc. C. E.

He entered Hamilton College, Clinton, N. Y., in 1847, and graduated in 1851, at the early age of nineteen. After graduation he went to Buffalo, where he studied law, and was admitted to the bar after a single year of hard work. The early labor by which he had accomplished this result at a period when boys are often still at school now told upon him, and his health gave way. He left Buffalo, returned to his father's home in Rome, and spent several months in the open air, under the general care of his father.

Feeling that his health required an outdoor life, he obtained a position in the engineer corps of the European and North American Railway, and spent the fall of 1852 and the following winter in the woods of New Brunswick and Maine This was the beginning of his work as an engineer, and he decided to abandon the law and make engineering his profession. He next spent the larger part of a year in the Astor Library in New York City, laying a theoretical groundwork for his new profession. In 1853 he went to the West, and worked for the Illinois Central Railroad on the location of its line in Southern Illinois. From there he went, in 1854, to the Galena and Chicago Union Railroad, which became the Chicago and Northwestern Railway in 1864 by a consolidation with other lines. He remained there until the latter part of 1864, and during the last four or five years he held the position of chief engineer.

It was while there that he was called on to do his first important work in bridge building. The bridge across the Mississippi River at Clinton was the second bridge across that river, the only earlier one being the old Rock Island bridge, the piers of which were founded on rock in shallow water. No such rock existed at Clinton, and the river was narrow and exceptionally deep. Mr. Pope used pile foundations, which have since become the standard practice on the upper Mississippi for all the piers except the pivot piers, and founded the pivot pier on a timber crib 400 ft. long, which not only carried the pier, but formed the draw protection. The same pier is still in good condition on the same foundation.

The draw of the Clinton Bridge was the first iron draw of importance built in the West; it consisted of two spans of Bollman trusses hung by hog chains from a central tower; it was built by contract by the Detroit Bridge and Iron Works. This contract shaped the remainder of Mr. Pope's life. He resigned his position as Chief Engineer of the Galena and Chicago Union Railroad, associated himself with the Detroit Bridge and Iron Works, and was elected a director of that company on February 9th, 1866. He opened an office in Chicago and remained there a year as the representative of the bridge works; he then went to Detroit and took direct charge of the engineering department. On May 7th, 1869, he was elected President of the company, and held this office until his death.

Mr. Pope's connection with this company, covering a period of nearly 30 years, so completely identified the man and the corporation that no life of Mr. Pope is complete which does not include a history of the bridge works. The Detroit Bridge and Iron Works was incorporated in the year 1863, and succeeded to the business of the bridge-building firm of Charles Kellogg & Co., this firm consisting of Mr. Charles Kellogg, now deceased, and Mr. William C. Colburn, who is still treasurer of the company. As early as 1861 this firm had constructed iron bridges on the Illinois Central Railroad and on the Galena and Chicago Union Railroad; they were of the Bollman pattern, and may be considered the pioneer iron bridges built in the West.

From February, 1866, to the time of his death, with occasional short vacations, Mr. Pope gave the most thorough personal supervision to all the work constructed by this company. In 1866 the Detroit Bridge and Iron Works took the contract for the superstructures of the bridges at Burlington and at Quincy, these being the first two all-iron bridges built across the Mississippi River; they also contained the first draw bridges of what may be called modern dimensions, and Mr. Pope's ability as an engineer was strikingly illustrated in the special features of these draws; their turn-tables were far in advance of others built up to that time, and they were equipped with a system of lifting cams at the ends which are still as good as anything in use; both these bridges were opened for traffic in 1868.

In 1869 and 1870 the Detroit Bridge and Iron Works built the bridge across the Mississippi River at Hannibal, taking the entire contract for both substructure and superstructure, the first time this had been done on any great western bridge. Subsequently the same company took the contract for the bridge across the Missouri River at St. Joseph, which was opened in 1873, building the entire substructure and superstructure. Col. Eddy D. Mason, M. Am. Soc. C. E., was the chief engineer of both of these bridges, and they are both monuments of the skill of the engineer proper and the engineering contractor. Although no complete bridges of equal magnitude were subsequently built by the Detroit Bridge and Iron Works, the company has continued steadily in the bridge business, confining itself principally to superstructure. Its shops at Detroit have always ranked among the best class of bridge shops, and engineers have always felt that Mr. Pope intended to furnish the best work his shops could produce.

Among the last important works constructed by this company may be mentioned the Ferris Wheel for the World's Columbian Exposition and the steel gates for the new lock on the St. Mary's Falls Canal.

Socially Mr. Pope was one of the most delightful of men. Always chary about asserting himself, he had to be drawn out; but the draw-

ing process disclosed his possession of a fund of the quaintest humor, which became on occasions exceedingly bright and sparkling. He was especially happy in a certain affectation of cynicism which was oddly at variance with his real habit of thought, and used it very effectively in the puncturing of shams, which was somewhat of a passion with him. He was always, however, tenderly careful of the feelings of others, and resented with all the force of his really strong nature the reckless habit into which so many have fallen in recent years of trifling in speech and otherwise with the reputation of others. He was not given as a rule to impassioned utterance; but those who knew him best will recall more than one occasion when he indulged in it in denunciation of criticisms upon individuals which he deemed unwarranted, inexcusable and slanderous.

Mr. Pope loved the quiet of his home and the companionship of those dearest to him. In that circle he was both loved for his earnest affectionate guidance as husband and father, and respected and looked up to for his wisdom, his learning, his keen sense of justice and his generous appreciation of all with whom he was closely associated. In the life of his own home the brightest and sweetest parts of his character were apparent. His life was entirely free from those unfortunate deficiencies of character and want of self control that often wear out the cheer and affection which are the necessary conditions of all true home life. His presence brought protection and happiness to his family and filled his home with cheerfulness and light.

He loved and was well acquainted with the best English literature, and this, with an unusual memory and facility of quotation, made him a most agreeable and instructive companion. During his residence in Detroit he was much sought after as a bright and witty speaker at public dinners.

Mr. Pope was married three times : In 1856 to Miss Harriet L. Bissell, daughter of Dr. Emory Bissell of Norwalk, Conn.; she died in the following year. In 1861 he married Miss Julia Bissell, a sister of his first wife ; she died in 1872. In 1882 he married Mrs. Martha E. Patterson, widow of Philo M. Patterson of Detroit and daughter of W. B. A. Bissell, Bishop of Vermont, who survives him. He leaves three daughters and one son, all of whom, with his widow, reside in Detroit. His son, Willard Pope, has followed his father's profession, and is now an engineer with the Detroit Bridge and Iron Works.

Mr. Pope became a member of the American Society of Civil Engineers August 7th, 1872; he was elected a Director in January, 1893, and had nearly completed his term of office at the time of his death.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

		Date of Membership.
Berg, Walter Gilman	261 West 52d St., New York City	Feb. 5, 1896
Brown, William Maxwell, Jr.	110 Boylston St., Boston, Mass.	Feb. 5, 1896
Grafton, Charles Edwin	Illinois Central Station, 12th St., Room 902, Chicago, Ill.	Jan. 1, 1896
Howe, Malverd Abijah	2008 N. 10th St., Terre Haute, Ind. — Assoc. M. / M.	May 7, 1890 / Jan. 1, 1896
Manning, William Thruston	Chief Engineer Baltimore and Ohio R. R., Baltimore, Md.	Feb. 5, 1896
Montgomery, John Alexander	2017 First Ave., Birmingham, Ala.	Jan. 1, 1896
Moran, Daniel Edward	Care Sooysmith & Co., Mills Bldg., New York City. — Assoc. M. / M.	June 3, 1891 / Jan. 1, 1896
Sloan, David	Illinois Central R. R., Chicago, Ill.	Jan. 1, 1896
Towl, Forrest Milton	Engineer National Transit Co., 26 Broadway, New York City	Feb. 5, 1896

ASSOCIATE MEMBERS.

Bauer, Jacob Louis	1135 Elizabeth Ave., Elizabeth, N. J.	Feb. 5, 1896
Brownell, Ernest Henry	174 Weybosset St., Providence, R. I.	Jan. 1, 1896
Fortin, Sifroy Joseph	825 Bushwick Ave., Brooklyn, N. Y.	Nov. 6, 1895
Lee, Wellington Barnes	Hillburn, N. Y.	Feb. 5, 1896
Miller, Clifford Neville	160 East 3d St., Covington, Ky. — J. / Assoc. M.	June 4, 1891 / Feb. 5, 1896
Mills, John Charles	4 Esplanade, Calcutta, India	Nov. 6, 1895
Villalon, José Ramon	Care Am. Soc. C. E., 127 East 23d St., New York City — J. / Assoc. M.	July 4, 1888 / Nov. 6, 1895

ASSOCIATE.

		Date of Membership.
Wells, Joseph Agur	311 Broadway, New York City	Jan. 7, 1896

JUNIORS.

Affelder, Louis Jacob	124 Sheffield St., Allegheny, Pa.	Feb. 4, 1896
Binion, Julius	Care Mrs. Freed, 182 East Broadway, New York City	Dec. 3, 1895
Burden, Morton	152 Sumac St., Wissahickon, Philadelphia, Pa.	Feb. 4, 1896
Firth, Elmer Wallace	473 14th St., Brooklyn, N. Y.	Jan. 7, 1896
Ives, Arthur Stanley	33 Sydney Place, Brooklyn, N. Y.	Jan. 7, 1896
Moisseiff, Leon Salomon	121 Forsyth St., Room 10, New York City	Dec. 3, 1895

CHANGES AND CORRECTIONS.

MEMBERS.

Baker, H. W.	3101 Washington Ave., St. Louis, Mo.
Bayliss, R. T.	The Montana Mining Co., Ltd., Marysville, Mont.
Bland, J. C.	Prin. Assistant Engineer P. C. C. & St. L. Ry., Pittsburgh, Pa.
Church, B. S.	36 West 12th St., New York City.
Garfias, I.	Postmaster-General, Mexico, Mexico.
Gay, Charles W.	Bank Bldg., 2d floor, 25 Exchange St., Lynn, Mass.
Hannaford, E. P.	2573 Catherine St., Montreal, Canada.
Harlow, J. H.	Chief Engineer Susquehanna Electric Power Co., Edgewood Park, Pa.
Hobson, Joseph	Chief Engineer G. T. Ry., Montreal, Canada.
Jackson, L. B.	City Engineer, Chicago, Ill.
Jennings, W. T.	Nelson's Bank Bldg., Toronto, Canada.
Johnston, J. Howard	Backus and Johnston, Lima, Peru.
Kastl, A. E.	815 Bort Bldg., 19 Quincy St., Chicago, Ill.
Lowrie, H. C.	Chief Engineer El Paso and North Eastern Ry., El Paso, Tex.
Lum, D. W.	Superintendent Bridges and Buildin Southern Ry., Washington, D. C.
Mais, H. C.	Prell's Building, 60 Queen St., 3d floor, Melbourne, Australia.

NICHOLS, O. F....................42 Gates Ave., Brooklyn, N. Y.
POWER, GEORGE C...............County Surveyor, Ventura Co., Ventura, Cal.
PEW, ARTHUR......................General Manager Playa de Oro Gold Mining Co., Tumaco, U. S. Colombia.
RAASLOFF, H. E. DE..............519 West Chestnut St., Louisville, Ky.
ROBERTS, E. P....................Sing Sing, N. Y.
SEAMAN, H. B....................40 Wall St., New York City.
SELLERS, WILLIAM...............1600 Hamilton St., Philadelphia, Pa.
SHMELEF, TH.....................Novorossiisk, Russia.
SMITH, H. DEW...................Shreveport, La.
STEVENS, F. S...................Division Engineer Reading Division P. & R. R. R., Reading, Pa.
WILSON, C. A....................Chief Engineer C. H. & D. Ry., Cincinnati, O.

ASSOCIATE MEMBERS.

CLARK, J. H.....................Massena, N. Y.
COCKROFT, C. A..................670 McDonough St., Brooklyn, N. Y.
CUMMINGS, R. A..................2105 Wallace St., Philadelphia, Pa.
HOVEY, O. E.....................Engineer in charge of office, Union Bridge Co., Athens, Pa.
KIRKPATRICK, W. G..............Canton, Miss.
SHERWOOD, G. W..................Fullerton, Cal.
TREADWELL, LEE ....513 Keith and Perry Bldg., Kansas City, Mo.

ASSOCIATE.

ABBOTT, E. L....................451 Racine Ave., Chicago, Ill.

JUNIORS.

ALBERTSON, CHARLES.............1930 Mt. Vernon St., Philadelphia, Pa.
BELL, G. J......................Care A. T. & S. F. R. R., Purcell, Ind. T.
EVANS, M. E ....166 East 64th St., New York City.
FAY, F. H.......................City Engineer's office, 165 City Hall, Boston, Mass.
FORD, W. H......................Hanover, N. H.
GREENALCH, WALLACE............Engineer H. R. & W. Co. M. R. R., Schuyville, N. Y.
KINSEY, W. R....................108 Fulton St., New York City.
WADDELL, MONTGOMERY..........29 Broadway, New York City.
WILKERSON, T. J................The Gillett Herzog Mfg. Co., Minneapolis, Minn.
WILSON, C. W. S................Assistant Engineer N. Y., N. H. and H. R. R., Worcester, Mass.

RESIGNATIONS.

MEMBERS.

	Date of Resignation
FORNEY, M. N	Dec. 31, 1895
MCCLURE, R. J	Dec. 31, 1895
MCKEE, S. B	Dec. 31, 1895
MOYLAN, JAMES	Dec. 31, 1895
POST, L. W	Dec. 31, 1895
SWIFT, A. J	Dec. 31, 1895

ASSOCIATE MEMBER.

KERR, H. H....Dec. 31, 1895

ASSOCIATES.

HAMMOND, H. B....Dec. 31, 1895
HENDRIE, J. S....Dec. 31, 1895
YOUNG, F. S....Dec. 31, 1895

JUNIORS.

GRIGGS, D. C....Dec. 31, 1895
VIER, HENRY....Dec. 31, 1895

DEATHS.

HILDRETH, RUSSELL WADSWORTH..Elected Junior Jan. 4, 1888; died Dec. 23, 1895.

POST, JAMES C....Elected Member Feb. 6, 1878 ; died Jan. 6. 1896.

PROSSER, THOMAS....Elected Fellow June 1, 1870 ; died Jan. 6, 1896.

WHITE, WILLIAM HOWARD....Elected Member March 5, 1873 ; died Dec. 11, 1895.

WILSON, JOHN A....Elected Member June 7, 1876 ; died Jan. 19, 1896.

ADDITIONS TO

LIBRARY AND MUSEUM.

From William A. Allen, Portland, Me.:
Thirty-fourth Annual Report of the Maine Central Railroad Company, for the year ending June 30th, 1895.
Thirty-seventh Annual Report of the Railroad Commissioners of the State of Maine for 1895.

From American Society of Mechanical Engineers, N. Y.:
Transactions, Vol. XVI, 1895.

From Board of Harbor and Land Commissioners, Boston, Mass.;
Annual Report for 1895.

From Board of Metropolitan Sewerage Commissioners, Boston, Mass.:
Seventh Annual Report for the year ending September 30th, 1895.

From Board of Trustees of the Sanitary District of Chicago:
Proceedings, December 11th, 18th and 24th, 1895, and January 1st and 3d, 1896.

From Board of Water Commissioners of St. Paul, Minn.:
Fourteenth Annual Report, December 1st, 1895.

From Cornell University, Ithaca, N. Y.:
Bulletins of Agricultural Experiment Stations, Nos. 104, 105, 106, 107 and 108.
Library Bulletin, Vol. III, No. 10.

From S. J. Fields, Buffalo, N. Y.:
Annual Report of the Department of Public Works of the City of Buffalo, N. Y., for the year ending December 31st, 1894.

From George S. Greene, Jr., N. Y.:
Annual Reports and Minutes of the Department of Docks for the years ending ing April 30th, 1893, 1894 and 1895.

From E. Haevens, Ghent, Belgium:
De la Résistance vive des Poutres sous l'action brusque ou au Passage des Charges.

From Harvard University, Cambridge, Mass.:
The Harvard University Catalogue, 1895-96.

From Clemens Herschel, N. Y.:
Reisen in die Marschländer an der Nordsee zur Beobachtung des Deichbaus, 1788.

From M. L. Holman, St. Louis, Mo.:
Annual Reports of the Water Commissioner of the City of St. Louis, for the fiscal years ending April, 1894, and 1895.

From Institution of Civil Engineers, London, Eng.:
List of Members, January 2d, 1896.

From A. Martens:
Umschau auf dem Felde des Materialprüfungswesens und verwandten Gebieten.

From McGill College and University, Montreal, Canada:
Calendar for Session 1895-96.

From S. F. Patterson, Concord, N. H.:
Proceedings of the Fifth Annual Convention of the Association of Railway Superintendents of Bridges and Buildings, October 15th and 16th, 1895.

From Railroad Commissioners of Connecticut, Hartford, Conn.:
Report for 1895.

From Frederick A. Riehlé, Philadelphia, Pa.:
The Digest of Physical Tests and Laboratory Practice, Vol. I, No. 1.

From John C. Smock, Trenton, N. J.:
Annual Report of the State Geologist of New Jersey for the year 1894.

From E. E. Russell Tratman, New York:
The Riley Elevated Railway System
Le Chemin de Fer à Cremaillère à Sumatra.
Statistics of the Colony of Tasmania for 1887.
Public Works Statement of Tasmania, June 5th, 1888.
Tasmanian Government Railways; General Manager's Report for 1887.
Report of Engineer-in-Chief of Public Works, Tasmania, for 1888.
Annual Report of the Commissioner for Railways, Queensland, for 1887.
Report of the General Manager of Railways, Cape of Good Hope, for 1892 and 1893.
Annual Report of South Australian Railway Commissioners for 1888-89, 1889-90 and 1890-91.
Return of the Railway Companies of the United Kingdom for the six months ending 30th June, 1890.
Strassenbahnen in Belgien, Deutschland, Grossbritannien, etc., etc. Statistisches und Finanzielles.
Rapport de E. A. Ziffer sur les divers moteurs mecaniques employés pour les Tramways et les Chemins de Fer secondaires.
Rapport de M. Neufeld sur "Quels sont les moyens de graissage employés pour les locomotives et pour les voitures?" etc.
Rapport de M. R. Draeger sur "Avez-vous fait l'essai de la ferrure à cordes?" etc.
Rapport de M. Baillot sur "Quelle est la composition normale de la ration de vos chevaux?" etc.
Rapport de M. P. Van Vloten sur "Decrivez le système de traction electrique que vous avez adopté," etc.
Rapport de M. Amoretti sur le question des travers de voies.
Annexe au rapport de E. A. Ziffer sur "Dans le cas de l'adoption d'un écartement de voie reduit, quels sont * * * les avantages ou les inconvenients relatifs des trois écartements reduits les plus usites: 1 m. .75 m. et .60 m.?"

Rapport de M. Hamelink sur "Avez-vous fait des experiences de chauffage des vos voitures et quels en ont été les resultats?" etc.

Rapport de M. Fischer-Dick sur "Decrivez, avec plans ou croquis a l'appui, les systèmes de voies métalliques que voies avez experimentés en indiquant la durée de votre experience," etc.

From U. S. Department of Agriculture, Washington, D. C.:

A Report on Irrigation and the Cultivation of the Soil thereby. Part I.

From U. S. Department of the Interior:

Report on Wealth, Debt and Taxation at the Eleventh Census, 1890.

From U. S. War Department, Chief of Engineers:

Twenty-three Reports on the Improvement of Certain Rivers and Harbors.

Annual Report upon the Improvement of Certain Rivers and Harbors in Oregon, Washington and Idaho.

From University of Wisconsin, Madison, Wis.:

Emergencies in Railroad Work.

From L. Van Wyck, Brooklyn, N. Y.:

Report of the Board of Commissioners of Electrical Subways of the City of Brooklyn, December 16th, 1895.

From W. Hasell Wilson, Philadelphia, Pa.:

Reminiscences of a Railroad Engineer.

From C. J. H. Woodbury, Boston, Mass.:

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PAPERS.

CONTENTS:

THE STRENGTH OF PILLARS.—AN ANALYSIS.

By LEOPOLD EIDLITZ.

TO BE PRESENTED MARCH 4TH, 1896.

When a pillar is compressed endwise by a force gradually increased to the breaking point, it is reasonable to assume that at the intrados of the pillar at the point of greatest deflection a strain has been set up which is as great as the stress causing rupture in a specimen of the material, the height or vertical length of which specimen does not materially exceed its smallest diameter. Without entering upon the question of the magnitude of this excess, which has been variously estimated, it may be safely placed at that point where the strain generated by the element of bending becomes inappreciable, and it is probable that endwise compression is always accompanied with bending strains. The question examined, however, in this paper is mainly what is the maximum strain in pillars compressed endwise in

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

the center of resistance by weights less than the breaking weights, or by weights not applied in the center of resistance.

Experiment shows that where a given pillar is deflected under increasing loads, the deflections increase at a greater ratio than the loads causing them, and the reverse is also true. The less the compressing force, the greater the ratio of reduction in the deflection.

The maximum strain at the middle of the intrados of a pillar bent to the breaking point may be assumed to be C, the ultimate resistance of the material to crushing. Let W be the breaking load of a solid 1-in. square pillar; the moment of resistance to bending is as follows :

If the vertical strain of the breaking load is deducted from the maximum strain C, the quantity $C - W$ remains to resist the bending moment δW, where δ is the breaking deflection and $\frac{d^3}{6}(C - W) = \delta W$, and as $d = 1$ the total strain $C = W(1 + 6\delta)$.

Now, let S be a strain $S < C$ and $W_1 < W$ and $\delta_1 < \delta$, then $S = W_1 \times (1 + 6\delta_1)$. Compare these two equations, and it appears that the relation of S to C can be as the respective weights W_1 to W only on the assumption that $1 + 6\delta_1 = 1 + 6\delta$, or that $\delta_1 = \delta$. It seems clear, therefore, that safe loads of pillars are not proportional to the breaking weights, but must be referred to a permissible maximum strain.

In building, the practice still prevails of considering cast-iron pillars planed top and bottom as subject to compound flexure as perceived in the testing machine. That this is not the case needs no special argument here, as the fact is universally recognized.

Breaking loads are computed by Gordon's and other formulas based upon Hodgkinson's experiments. In these experiments endwise compression was applied to the specimen as nearly as practicable in the center of resistance, or at least in the center of gravity of the pillar tested, which is also the center of resistance, unless the material is heterogeneous.

On pages 130 and 131 of this paper is an analysis of the bending strains caused by eccentric loads. The exact relation of the eccentric breaking load to the concentric breaking load is expressed in a formula.

Endwise Compression.

A specimen of cast-iron 1 in. square is extended 0.0017 of its length by a force of about 16 000 lbs. applied at the ends, and when so extended it is torn asunder. If the specimen is 5 ins. long, its extension

under a tensile strain of 16 000 lbs. is $5 \times 0.0017 = 0.0085$; when 10 ins. long, it extends under the same strain $10 \times 0.0017 = 0.017$; and when 100 ins. long, it is extended $100 \times 0.0017 = 0.17$ in., but in each event it requires a strain of neither more nor less than 16 000 lbs. to cause rupture.

A short specimen of cast-iron of the same sectional area of 1 in. is crushed by a compressing force of about 96 000 lbs.; but as the specimen becomes longer, the force required to disintegrate it becomes rapidly less. Thus, when the specimen is 5 ins. long, it will break under 85 000 lbs.; when 10 ins. long, under 45 000 lbs.; when 15 ins. long, under 30 000 lbs.; when 20 ins. long, under 23 000 lbs.; when 40 ins. long, under something less than 8 000 lbs.; and when 80 ins. long, under 2 000 lbs.

Now the main difference in the behavior of two specimens acted upon by compression and tension is that the latter specimen remains in a straight line during the application of force, while the former becomes curved. It is said, therefore, that a pillar or strut bends or deflects under endwise compression. Unequal compression, though not a primary cause, is a result of the process of bending. This involves a brief consideration of the nature of elasticity.

Elasticity is the internal force which in matter persists in maintaining atomic or molecular relations. The sum of persistence which a given kind of matter is capable of constitutes its potential elasticity. External force applied to given matter brings into activity an equal amount of elastic force, and while this external force remains in action, the potential energy of elasticity of the matter in question is reduced by that amount. When the external force is equal to the internal potential resistance of elasticity, the specimen is on the point of disruption. Any additional amount of external force, no matter how small, will cause disruption.

The exertion of the elastic force inherent in matter is always accompanied with fatigue. This means that the potential energy of elastic force is reduced by exertion. The amount of fatigue caused by comparatively small increments of external force (as compared in magnitude with the total potential energy of the elastic force of a given material) is imperceptible to the senses unless scrutinized by special sensitive instruments of measurement. The extent to which this is the case is known as the elastic limit of the material, and the amount

of fatigue which becomes perceptible beyond the elastic limit is called the permanent set. Within the elastic limit the increments of compression and extension are nearly the same for every equal amount of additional external force applied, so much for every additional 1 000 lbs. This is called uniform elasticity. Beyond the elastic limit, compression and extension increase with every additional equal amount of external force applied. This is called variable elasticity.

Within the elastic limit each pound of force exerted results in an equal amount of compression, or an equal amount of extension, though the amounts of compression and extension are never the same in any one material. In matter uniformly elastic, the number of pounds of external force divided by the resulting compression is a constant, or, if divided by the resulting extension, the quotient will be another constant. These constants are called the moduli of elasticity of the given material. So each material has its special moduli of elasticity for compression and for extension, and if the modulus of elasticity is expressed by E, the weight by W, the amount of compression by C, and that of extension by T, the modulus of elasticity for compression by E_c and that for tension by E_t, it follows:

$$\frac{W}{C} = E_c \quad \text{and} \quad \frac{W}{T} = E_t$$

$$W = E_c\, C \quad \text{``} \quad W = E_t\, T$$

$$\frac{W}{E_c} = C \quad \text{``} \quad \frac{W}{E_t} = T$$

Within the range of variable elasticity each number of pounds of strain has its special modulus of elasticity; hence, the convenience of its use in analysis is lost, and stress must be referred directly to the amount of the compression or extension caused by it in matter.

The compression per square inch area caused in cast-iron by weights ranging from 1 000 to 96 000 lbs., and those of wrought iron from 1 000 to 52 000 lbs., as presented in Tables Nos. 1 and 2, are derived from curves based upon the results of Hodgkinson's experiments.

Table No. 1 gives in column 2 the compression of 1 in. area of cast-iron for weights from 96 000 to 1 000 lbs., also in column 3 the compression due to the last 1 000 lbs. applied. It will be seen from the last that the elasticity of compression of cast-iron is variable throughout.

Table No. 2 gives in column 2 the compression of 1 in. area of wrought iron for loads given in column 1; also in column 3 the compression due to the last 1 000 lbs.

It will be seen that for wrought-iron pillars the additional increment of compression for every additional 1 000 lbs. is 0.00004 up to 12 000 lbs., and 0.00005 from 12 000 to 24 000 lbs. Twenty-four thousand to 28 000 lbs., therefore, is accepted as the limit of elasticity of wrought iron. The average increase per 1 000 lbs. up to 24 000 lbs. is 0.000045; therefore, 1 000 $\div$ 0.000045 gives the modulus of elasticity for the compression of wrought iron as 22 000 000.

For the extension of wrought iron within the elastic limit the modulus is found by experiment to vary between 25 000 000 and 28 000 000.

Deflection.

For greater convenience of analysis and of arriving at tables which give the breaking and safe weights per inch area for lengths expressed in terms of diameters or radii of gyration, let the diameter of the pillars be $d = 1$; let them be solid and square in form; hence, the sectional area will also be $a = 1$; the moment of inertia will be $\frac{1}{12}$; the moment of resistance $\frac{1}{6}$, and the pillar length expressed in diameters will represent so many inches.

If a pillar is compressed vertically by its breaking weight and is in some way prevented from bending, its potential elastic energy for compression still remaining is $C - W$, where C is the crushing weight of the material, and the potential energy of tension still remaining is $T + W$ when T represents the ultimate resistance of the material to tension.*

If, now, the pillar is left free to bend, then at the breaking point this remaining potential energy is exhausted; hence, the bending moment $\delta\ W$, δ being the deflection, is in equilibrium with the potential energy multiplied by the moment of resistance; hence,

$$\delta\ W = \frac{1}{6}(C - W) = \frac{1}{6}(T + W) \text{ and } \delta = \frac{C - W}{6\ W} = \frac{T + W}{6\ W}$$

* When a body is compressed or extended by a force less than its ultimate resistance to compression or tension, the balance of compression or extension possible may be considered to be its potential energy for resisting another external force.

Let a body capable of an ultimate resistance to compression C, or of resistance to extension T, be compressed in the one instance by a force W, or extended by a force W, in either event its potential energy will be $C - W$ or $T - W$. But if the external force is one of compression, in either case the potential energy of resistance to compression is $C - W$, and that to extension is $C + W$.

Under conditions of uniform elasticity this value of δ is absolutely correct. But inasmuch as elasticity is variable, it would be true only if the horizontal sectional planes drawn transversely to the pillar length were to become curved during the process of bending.

To ascertain exact deflections related to certain breaking loads from an assumed condition of compression, or of compression and tension at the middle of a pillar bent to the breaking point, the following process is practicable:

Let *a b c d* (Fig. 1) represent a diagram of compression at the middle of a square cast-iron pillar 1 in. on a side bent to the breaking point. The stress at *b*, the intrados of the pillar, is assumed to be 96 000 lbs., the crushing stress of the material. The compression due to a stress of 96 000 lbs., as given in the table, is 0.026. At the point *a*, the extrados of the bent pillar, the compressive strain is assumed to be 32 000 lbs. Compression at the intervening points between *a* and *b* is as marked upon the vertical lines drawn at those points, and the strain due to these respective compressions, as given in Table No. 1, is the number of pounds marked at the bottom of the vertical lines. *A B C D* (Fig. 1) represents a strain diagram at the middle of the pillar divided into ten laminas representing the mean stress of each lamina. This diagram gives by computation an area of 71 080 lbs. and a center of gravity 0.0692 distant from the axis of the pillar, which distance constitutes the deflection.

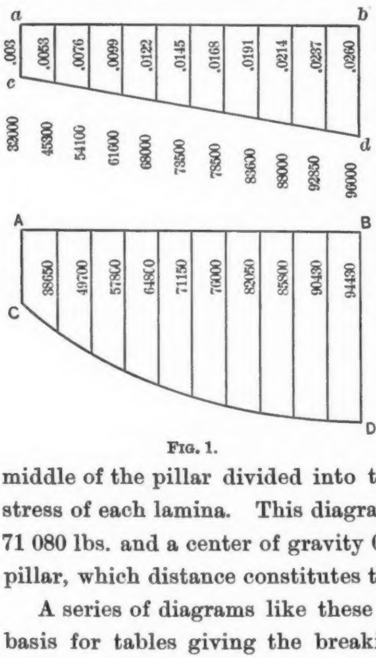


FIG. 1.

A series of diagrams like these with varying strains at *a* forms a basis for tables giving the breaking weight, deflection, and, as will be shown hereafter, the breaking radius and breaking length of all possible pillars.* Tables Nos. 3 and 4 have been prepared in this

* This process of ascertaining the breaking weights, deflections, radii and corresponding breaking lengths, as given in Tables Nos. 3 and 4, is absolutely correct. The method first stated (page 123) of computing deflection by the formula $\delta = \frac{C - W}{6\,W}$ is less accurate and so is the resulting determination of the radius, and consequently of the pillar length. The result is that for given pillar lengths the breaking weights are less than those based upon

manner; Table No. 3 is for cast-iron pillars, and Table No. 4 for wrought-iron pillars.

RADIUS.

Let $a\ b\ c\ d\ g$ (Fig. 2) represent the strain diagram at the middle of a pillar bent to the breaking point under a breaking load W $a\ b = T$ (tension) and $d\ g = C$ (the ultimate crushing resistance of the material). Then $m\ b\ o\ n\ g$ represents the total resistance to bending, and $a\ d\ n\ m$ the resistance to vertical compression.

If the latter is assumed to pervade the whole pillar, the former determines the varying positive and negative strains and their accompanying compression and extension, which constitute the elements that determine the radius.

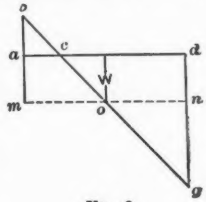


FIG. 2.

At the intrados, the pillar always shortens in bending. At the extrados, it may shorten less, not at all, or it may lengthen by tension. The shortening at the breaking point at the middle of the pillar is $d\ g = c$. That part of $d\ g$ which represents resistance to bending ($n\ g$) becomes continually less at points approaching the top and bottom of pillar, and is nil at the top and bottom.

The average of the strains in point (if the bending curve of the pillar is assumed to be the same as that of a rectangular beam under a transverse load in its center) is $p\ (C - W) = 0.6125 \times (C - W)$. A circular curve drawn through the top, the bottom, and the middle of the intrados of a pillar at the breaking point therefore represents a uniform strain of compression of $W + p\ (C - W)$, and a similar circular curve at the extrados represents a uniform strain of

the assumption of a curved resistance diagram at the middle of the pillar at the point of breaking. Exactly how much this difference amounts to may be ascertained by comparing Tables Nos. 1 and 2 with Tables Nos. 3 and 4.

Figs. 3 and 4 show the curves of breaking weights for respective pillar lengths in accordance with Tables Nos. 1 and 3 and Nos. 2 and 4 for more convenient comparison. But inasmuch as breaking weights are of themselves no criterion of safe loads, the formula $\delta = \frac{C - W}{6\ W}$ has been used in the following analysis of deflections under loads less than the breaking weight with results that show no material difference when applied to either of Tables Nos. 1 and 3 or Nos. 2 and 4, except in the case of long wrought-iron pillars, which show somewhat increased safe loads when computed in accordance with Table No. 4.

Inasmuch as the breaking loads for both cast and wrought iron, as given in Tables Nos. 1 and 2, more nearly coincide with the results of Hodgkinson's experiments, and inasmuch as a moderate reduction of the safe loads of long columns secures reasonably moderate deflections, it has been deemed best to compute the tables of safe loads in accordance with Tables Nos. 1 and 2.

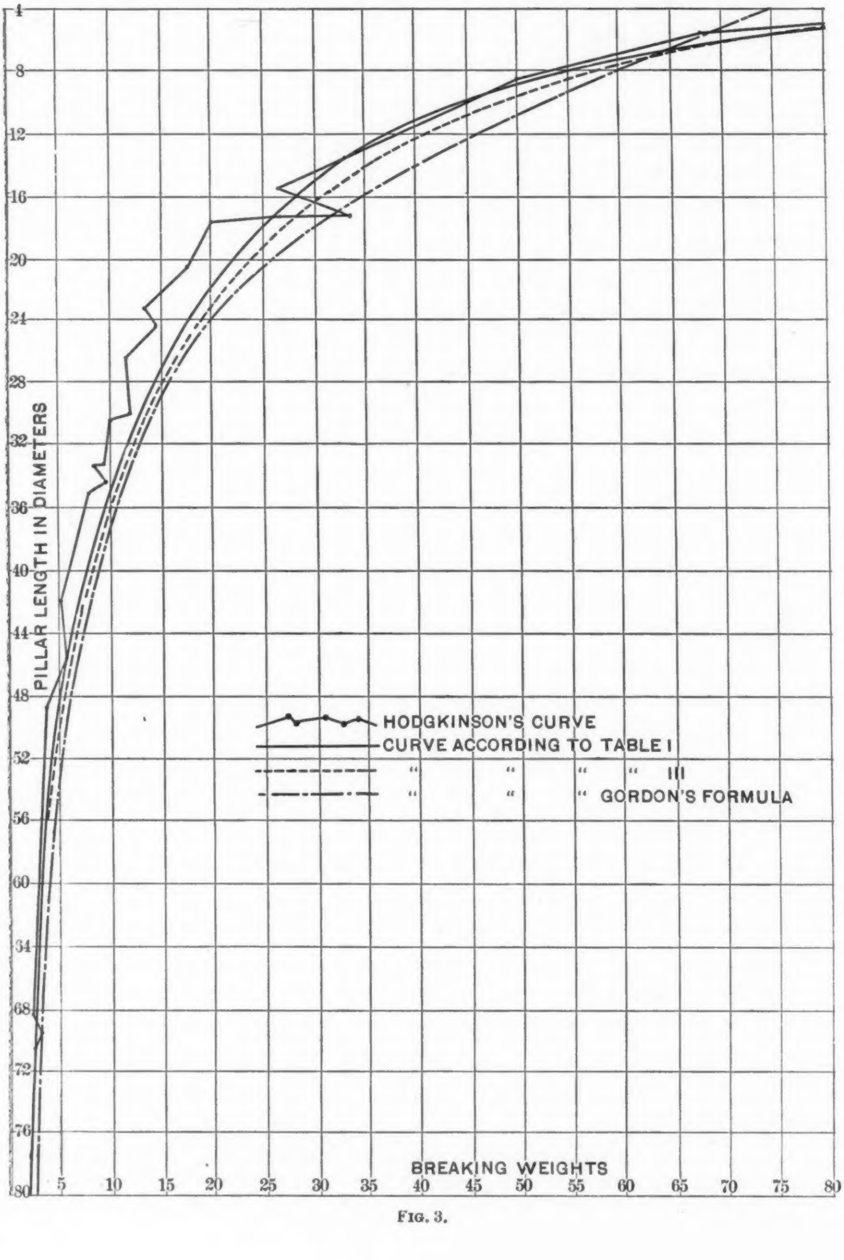
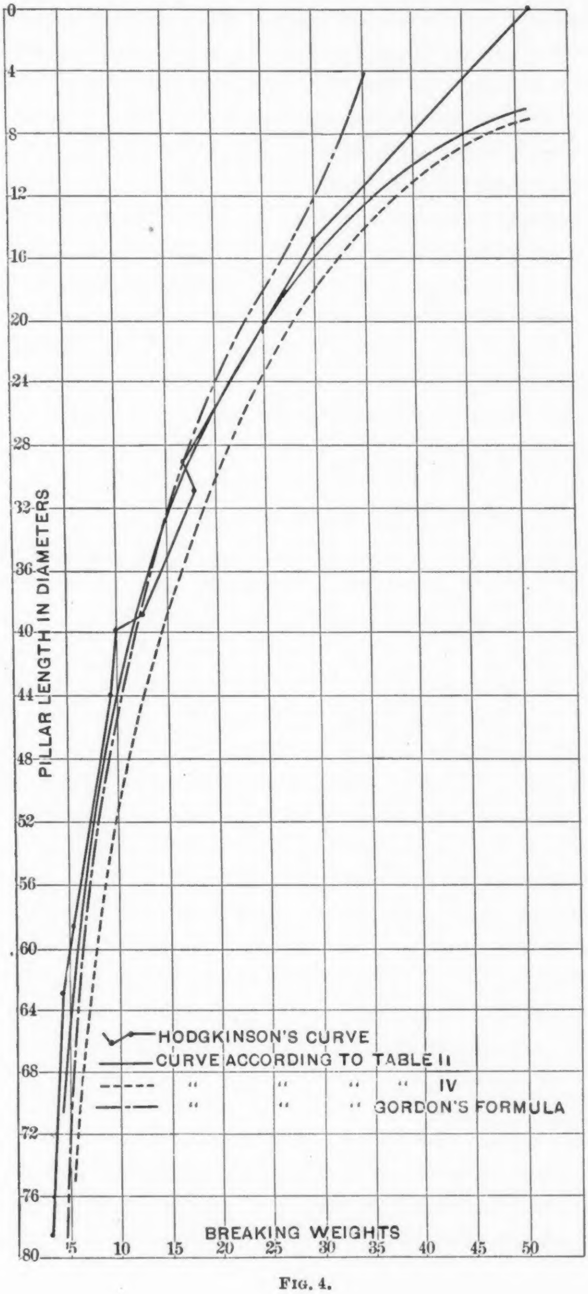

PILLAR LENGTH IN DIAMETERS
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
HODGKINSON'S CURVE
CURVE ACCORDING TO TABLE I
" " " " III
" " " GORDON'S FORMULA
BREAKING WEIGHTS
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

FIG. 3.



PILLAR LENGTH IN DIAMETERS
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
HODGKINSON'S CURVE
CURVE ACCORDING TO TABLE II
" " " IV
" " GORDON'S FORMULA
BREAKING WEIGHTS
5
10
15
20
25
30
35
40
45
50

FIG. 4.

$W - p\ (C - W)$ which may be negative or positive, a strain of compression or tension. The radius and deflection of a pillar are the sole elements of its length (as will be shown hereafter), and though the circular curve which passes through the middle and top and bottom differs from the bending curve, this difference of length may be neglected without appreciable error.

The radius of a circular curve is the radius of any portion of it, being dependent upon the compression at the intrados, and the compression or extension at the extrados. If compression be expressed by the sign C_p and extension by the sign E_x and $a\ b\ c\ d$,

FIG. 5.

Fig. 5 represents a portion of the pillar in a circular curve, of which $f\ g$ is the axis, then $o\ g$ is the radius R, and if the diameter of the pillar is d, then $a\,c;\ b\,d = R + \frac{d}{2} = R - \frac{d}{2}$,

$$\text{and if } d = 1 \text{ then } R = \frac{a\,c + b\,d}{2\ (a\,c - b\,d)}.$$

Let the height of $a\ b\ c\ d$ be considered as 1 prior to deformation by bending, then $a\,c = 1 - C_p\ [W - p\ (C - W)]$, and

$$b\,d = 1 - C_p\ [W + p\ (C - W)] \text{ and}$$

$$R = \frac{2 - [C_p\ [W - p\ (C - W)] + C_p\ [W + p\ (C - W)]]}{2\ [C_p\ [W + p\ (C - W)] - C_p\ [W - p\ (C - W)]]}$$

When $p\ (C - W)$ is greater than W, then $W - p\ (C - W)$ becomes negative and denotes tension.

Example.—To find the radius for a breaking weight $W = 48\,000$ lbs., the ultimate resistance of the material to crushing being $C = 96\,000$ lbs. $C - W = 48\,000$ and $p\ (C - W) = 29\,400$; $W + p\ (C - W) = 48\,000 + 29\,400 = 77\,400$ lbs., $W - p\ (C - W) = 18\,600$ lbs. By Table No. 1 the compression for 77 000 lbs. is 0.016045. For the additional 400 lbs. at the rate of the last 1 000 lbs., which is 0.000454; it is 0.000182; therefore, for 77 400 lbs. the compression is $0.016045 + 0.000182 = 0.016227$. The compression due to 18 600 lbs., the uniform stress at the extrados by Table No. 1, is 0.001606; hence,

$$R = \frac{2 - (0.001606 + 0.016227)}{2\ (0.016227 - 0.001606)} = \frac{2 - 0.017833}{2\ (0.014621)} = 67.7.$$

Table No. 1 gives the uniform strains for cast-iron at the intrados in column 6 and those of the extrados in column 7. Column 4 of the same table gives the strain at the middle of the extrados. It will be observed that this strain is one of compression throughout the pillar

area when the breaking weights range from 96 000 lbs. down to 48 000 $= \frac{1}{2} C$; at 48 000 lbs. the stress in the middle of the pillar at the extrados is nil. From 48 000 down to 40 000 lbs. breaking weight, the strains at the middle at the extrados are tensional, beginning with 0 and ranging up to 16 000 lbs., the assumed ultimate resistance of the material to tension. At the intrados in the middle of the pillar down to a breaking load of 40 000 lbs. the strain is constant at the ultimate resistance of the material to crushing, which is assumed at 96 000 lbs. When cast-iron pillars exceed a length of 11.3 diameters, they break under a load less than 40 000 lbs. by rupture at the extrados; hence, the strain at the middle of the intrados becomes less than 96 000 lbs., and, as is shown by Table No. 1, when a 1-in. square cast-iron pillar is 115.1 ins. long, it breaks by tension at the extrados, while at the middle of the intrados the strain of compression has run down to 18 000 lbs.

It may be noticed also that deflection becomes greater when the pillar becomes longer and the breaking weight becomes less. As the breaking weights descend from 96 000 to 1 000 lbs., deflection begins with 0.00175 and ends with 2.83333. The radius, on the other hand, is largest with the greatest breaking weight and becomes less when the breaking weight becomes less. It is least at a breaking weight of 48 000 lbs. From this point downward in the scale of breaking weights the radius becomes larger again.

Both radius and deflection depend upon the resistance of the pillar to bending at the breaking point. This resistance is the potential energy of the material still remaining after the vertical force of endwise compression is deducted from the ultimate strength of the material; $C - W$ or $T + W$ are the measure of this potential energy. The greater the elastic force of $C - W$ or $T + W$, the greater the deflection.

This accounts for the fact that pillars break with smaller deflections than beams under a transverse load. In the latter, resistance to bending is the total ultimate strength of the material, while in the former a portion of this strength is consumed by endwise vertical compression.

Length of a Pillar.

Let $a\,b$ (Fig. 6) represent a small portion of a circular curve, the radius of which is $a\,o$, and its diameter $a\,d$; then the curve $a\,b$ may without serious error be considered as a straight line, and the triangle

$a\,c\,b$ is homologous to the triangle $a\,b\,d$ and $a\,c : a\,b = ab ; b\,d$ and $a\,c \times b\,d = a\,b^2$.

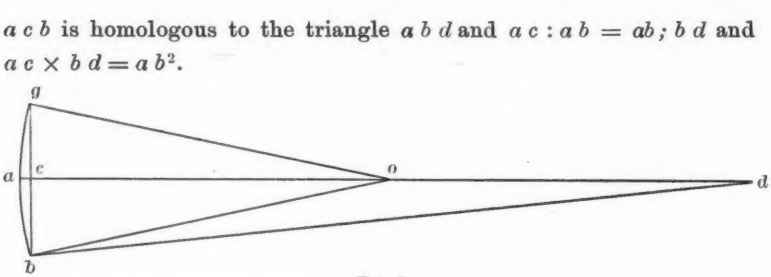


FIG. 6.

Let $b\,g$ represent the length of a pillar bent with a deflection $\delta = a\,c$ and $b\,g = L$, hence $L = 2\,a\,b$ and $a\,b^2 = \frac{L^2}{4}$ and $b\,d = 2\,R$; then by substituting these values of $a\,c$, $b\,d$ and $a\,b$ in $a\,c \times b\,d = a\,b^2$.

$$2\,R\,\delta = \frac{L^2}{4} \text{ and } L^2 = 8\,R\,\delta \text{ and } L = \sqrt{8\,R\,\delta}.$$

Tables Nos. 1, 2, 3 and 4 give the length of pillars corresponding to the respective breaking weights for solid square cast and wrought-iron pillars, on the assumption of straight and curved diagrams of resistance at the middle of the pillar. Fig. 3 gives resistance curves at the breaking point of solid square cast-iron pillars of all lengths and breaking weights in accordance with Tables Nos. 1 and 3, also with Gordon's formula and Hodgkinson's experimental results. Fig. 4 gives the same for solid square wrought-iron pillars.

ECCENTRIC LOADS.

The foregoing analysis refers to pillars compressed endwise by a force acting in the center of gravity of the resistance, which in a homogeneous pillar is also the center of gravity of its cross-section. In that case stress is assumed to be equally distributed at the top of the pillar, also at the bottom.

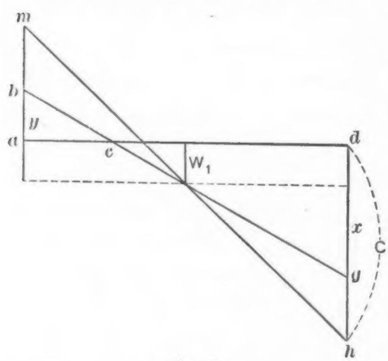


FIG. 7.

When the force compressing the pillar is not acting in its center, and the eccentricity is n (a fraction of its diameter), then the distribution of stress at the top of the pillar is not uniform, but may be expressed by the diagram, Fig. 7, where W_1 being 1, x denotes strain

of compression at the intrados x, 1 or $x\ W$, and y the strain at the extrados, y, 1 or $y\ W_1$; the latter may be a strain of compression or tension or nil, and

$$\frac{x-1}{6} = \frac{y+1}{6} = n, \text{ and}$$
$$x = 6\,n + 1 \text{ and } y = 6\,n - 1.$$

At the point of breaking, the strain at the intrados in the middle of the pillar has increased to C, the crushing strain of the material, hence the moment due to deflection δ_1 is resisted by $\frac{g\ h}{6}$. The resistance to the total bending is therefore

$$\frac{C - W_1}{6} = (n + \delta_1)\ W_1$$

Let $a\ b\ c\ g$ (Fig. 8) represent the upper half of the pillar bent by the load W_1, placed upon the top of the pillar at the distance n from its center of resistance (where n represents a fraction of the diameter of the pillar), and let δ be the resultant deflection and $\frac{C - W_1}{6}$, the resistance to bending

$$\frac{C - W_1}{6} = (n + \delta_1)\ W_1 \ldots\ldots (1)$$

Let W, the breaking weight of the pillar in question, when acting in the center of resistance, be placed at the center, the moment of resistance to bending will be $\frac{C - W}{6}$ and the pillar will bend with a deflection $\delta < \delta_1$ and

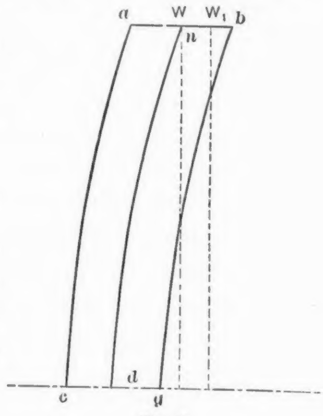


FIG. 8.

$\delta\ W : \delta_1\ W = C - W : C - W_1$ or $\delta : \delta_1 = C - W : C - W_1$ and $\delta_1 = \delta\, \frac{C - W_1}{C - W}$, but as $\delta = \frac{C - W}{6\ W}$, then $\delta_1 = \frac{C - W_1}{6\ W}$.

When this value of δ_1 is introduced in equation (1), then

$$W_1 = \pm \sqrt{\left(\frac{C + W + 6\,n\ W}{2}\right)^2 - C\ W} + \frac{C + W + 6\,n\ W}{2}$$

In the case of the cast-iron pillars, the bending resistance is $\frac{T + W}{6}$, then

$$W_1 = \pm \sqrt{\left(\frac{W - 6\,n\ W - T}{2}\right)^2 + T\ W} + \frac{W - 6\,n\ W - T}{2}.$$

Table No. 5 gives the breaking weights for cast-iron pillars of length, in diameters varying from 5 to 50, when compressed by loads placed to one side of their neutral axis, for eccentricities of 0.1, 0.3, 0.5, 0.7 and 1.0. Table No. 6 gives breaking loads for wrought-iron pillars for lengths in diameters from 7 to 44 for the same eccentric loads.

THE DEFLECTION AND RADIUS CAUSED BY $W_1 < W$ WHEN PLACED IN THE CENTER OF RESISTANCE.

Let a pillar of the length L, breaking deflection δ, breaking weight W, and breaking radius R, be bent to a deflection $\delta_1 = \frac{\delta}{2}$ or $\delta_{11} = \frac{\delta}{4}$; the respective weights will be less than W, say $W - a$, and $W - (a + b)$ and the corresponding bending moments are $\delta_1 (W - a)$ and $\delta_{11} (W - a - b)$ and the bending radii R_1 and R_{11}. Inasmuch, however, as L is constant, then $L^2 = 8 \delta R = 8 \delta_1 R_1 = 8 \delta_{11} R_{11}$ or $\delta R = \delta_1 R_1 = \delta_{11} R_{11} = \ldots \delta_n R_n$. The value of $R\ R_1\ R_{11}$ is always a function of the respective deflections, δ, δ_1 and δ_{11}, irrespective of bending weight.

The bending moment, on the other hand, depends on the bending weight as well as on the deflection. The greatest bending strain occurs at the middle of the intrados of the pillar, and at the breaking point it is C, the crushing resistance of the material when deflected to the point δ. With a deflection δ_1, the greatest stress at the middle of the intrados will be $S < C$, and with a deflection δ_{11} it is $S_{11} < S$.

Comparing the bending moments with the respective resistance,

$$\frac{C - W}{6} = \delta\ W; \frac{S - W_1}{6} = \delta_1\ W_1 = \delta_1 (W - a) \text{ and}$$

$$\frac{S_{11} - (W - a - b)}{6} = \delta_{11} (W - a - b) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

If elasticity is assumed to be uniform, and $S - W$ is the internal stress which resists bending and the compression due to $S - W$ is $\frac{S - W}{E}$, E being the modulus of elasticity of the material in question, the radius may be found by comparing the length of any unit of measure at the intrados with a corresponding unit of the pillar axis, without regard to the vertical compression which is uniformly distributed. In that case compression at the pillar axis is nil and at the intrados it is $\frac{S - W}{E}$ as stated previously, and $1 - \frac{(S - W_1)}{E} : 1 = R_1 - \frac{d}{2} : R_1$ and the radius $R_1 = \frac{1E}{2\,p\,(S - W_1)}$, hence

$$R_1 = \frac{E}{2p\,(S - (W - a))} \text{ and } R_{11} = \frac{E}{2p\,(S_{11} - (W - a - 6))} \text{ and}$$

$$R_1 : R_{11} = S_{11} - (W - a - b) : S_1 - (W - a) \ldots\ldots (3)$$

From equation (2) :

$$S = (W - a)\,(1 + 6\,\delta_1) \text{ and } S_{11} = (W - a - b)\,(1 + 6\,\delta_{11})$$

and as $\delta_1 = \frac{C - W}{12\,W}$ and $\delta_{11} = \frac{C - W}{24\,W}$

$$S = (W - a)\left(1 + \frac{C - W}{2\,W}\right) \text{ and}$$

$$S_{11} = (W - a - b)\left(1 + \frac{C - W}{4\,W}\right) \ldots\ldots (4)$$

Substitute values of S and S_{11} in equation 3.

$$R_1 : R_{11} = (W - a - b)\left(1 + \frac{(C - W)}{4\,W}\right) - (W - a - b) :$$

$$(W - a)\left(1 + \frac{C - W}{2\,W}\right) - (W - a)$$

$$R_1 : R_{11} = (W - a - b)\,\frac{(C - W)}{4\,W} : (W - a)\,\frac{(C - W)}{2\,W}$$

$$R_1 : R_{11} = \frac{(W - a - b)}{2} : W - a$$

$$R_{11} = 2\,R_1\,\frac{W - a}{(W - a - b)} \ldots\ldots (5)$$

But inasmuch as $R_{11}\,\delta_{11} = R_1\,\delta_1$ and $\delta_1 = 2\,\delta_{11}$, hence $2\,R_1$ must be $= R_{11}$ in all cases. Therefore equation (5) is true only when a and b are nil.

At all points short of the breaking deflection it is known by experiment that there is no equilibrium during the process of bending under a breaking weight until the breaking deflection is reached, and that resistance to the bending moment is least at the smallest deflection, and becomes greater as the breaking deflection is approached.

Yet at half the breaking deflection $\delta_1 = \frac{\delta}{2}$

$$\delta_1\,W = \frac{S - W}{6};$$

at the breaking point $\delta\,W = \frac{C - W}{6}$; hence,

$$S - W : C - W = \delta_1\,W : \delta\,W = 1 : 2, \text{ and}$$

$$S - W = \frac{C - W}{2}.$$

If $S - W$ represented an internal force of resistance to the bending moment, then experiment would show a condition of equilibrium ; but this not being the case $\frac{S - W}{6}$ only partially consists of compression, a compression due to a strain less in magnitude than $S - W$, in fact a stress equal to $(W - a)$.

But $S - W$ is the true measure of the radius, hence the radius is the result of two forces. The one is $\delta_1 \ (W - a)$ which is the force of compression at the intrados in excess of that at the pillar axis, and the force $\delta_1 \ a$, which for the present may be attributed to the vertical stress of a weight $W - a$ without a definition of its exact nature, simply because endwise compression is the sole cause of any and all deformation of the pillar. An example will illustrate the foregoing more clearly:

Given a solid 1-in. square cast-iron pillar and 9.5 ins. long, then $C = 96\,000$ lbs., $W = 48\,000$ lbs., $\delta = 0.16666$, $R = 67.7$ and $\delta \ R = 11.3$; consequently any $\delta_1 \ R_1$ must also be equal to 11.3, and if $\delta_1 = \frac{\delta}{2} = 0.08333$, then $R_1 = 135.4$.

The value of W_1 being unknown further than that it is less than W, it must be something between 48 000 lbs. and nil. Whatever its magnitude; when $\delta_1 = \frac{\delta}{2}$, the radius R_1 must be 135.4.

Let W be 48 000 lbs., then $\delta_1 \ W = \frac{\delta \ W}{2}$ and as $\delta \ W = \frac{C - W}{6}$ then $\frac{\delta_1}{2} \ W = \frac{C - W}{12} = \frac{S - W}{6}$ where S is the total strain at the intrados when the deflection is $\delta_1 = 0.08333$, and $\delta_1 \ W = \frac{S - W}{6} = 4\,000$ lbs., and $S - W = 24\,000$ lbs.; hence $S = 72\,000$ lbs. S being known, the radius may be computed by the formula developed on page 125, by substituting S for C and

$$R_1 = 2 - \frac{C_p \left[(W - p\,(S - W)) + C_p\,(W + p\,(S - W))\right]}{2\left[C_p\,W + p\,(S - W) - C_p(W - p\,(S - W))\right]} = 140.3.$$

If $W = 44\,000$ lbs., $S = 66\,000$ lbs. and $R_1 = 172.7$.

If $W = 40\,000$ lbs., then $S = 60\,000$ lbs. and $R_1 = 219.5$.

If $W = 39\,070$ lbs. (which is, as will appear hereafter, to be the true weight which bends the pillar with a deflection $\delta = 0.08333$), then $S - W = 19\,534$ and $S = 58\,606$ and $R_1 = 233.1$.

Table No. 7a gives the values of S, $(S - W)$ and R for possible W_1 from 48 000 down to 24 000 lbs.

Inasmuch as the radius corresponding with a deflection $\delta_1 = 0.08333$

cannot be more than 135.4, it appears that whatever the bending weight which results in a resistance of $\frac{S - W_1}{6}$ the radius to correspond with that resistance is less than the radii shown in Table No. 7A, whence $S - W_1$ must be correspondingly greater than those appearing in the table.

Whatever the value of $S - W_1$, or X as it will be called hereafter, it is greater than the bending moment.

It constitutes the resistance to a force acting transversely to the pillar length to the extent of the deflection. It appears that when a pillar bends under any weight W or $W_1 < W$ the deflection is not owing primarily to diversity of compression, but to a sliding motion of the particles in a horizontal direction which results in a displacement of the compressing force to one side of the pillar axis, hence unequal compression of the transverse area of the pillar.

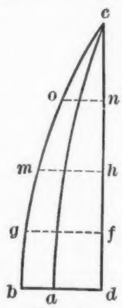


FIG. 9.

In Fig. 9 the curve of deflection *a c* is projected, which is due to unequal compression, and *b c* is the curve of total deflection. This means that $b\,d = \delta_1$ (the actual deflection), and *a d* is that part of the actual deflection which is due to diversity of compression, and it means further that during the process of bending the point *d* has moved horizontally to *b* while *c* remained stationary, also that the points of *f*, *h* and *n* have moved respectively to *g*, *n* and *o*.

If the pillar is assumed to be compressed in a testing machine, *c* is stationary and *d*, *f*, *h* and *n* are movable. This motion doubtless begins with any pressure, no matter how small, and when W_1 is very small, *b d* also will be proportionately small. Yet as the line of compression continues to be a straight line between the poles of the pillar axis, and as the pillar axis in the meantime has become a curve, unequal compression is the result. It will be shown hereafter that when the compressing force is very small as compared with the breaking weight, *a d* is also very small as compared with *b d* and when the compressing force becomes the breaking weight, $a\,b = b\,d$.

Resistance to Bending, for $W_1 < W$.

At the breaking point the amount of bending depends upon the bending weight and upon the strength of the material; this means the total potential energy of the material still remaining after a portion of

it has been consumed in resisting vertical stress. The formula $\delta = \frac{C - W}{6W}$ means that a pillar bends at the breaking point as much as the resistance of the material will permit and inversely as the bending force. Deflection at the breaking point is an element in determining the length of the pillar, and deflection is as the square of the pillar length limited by the radius, which is also as the square of the pillar length limited by the deflection. Elasticity does not enter into determining the breaking deflection. But when it is intended to compare bending and resistance to bending for weights less than the breaking weight, elasticity becomes an element in comparing the condition of it for a weight $W_1 < W$ with a corresponding condition at the breaking point.

If resistance to bending under the weight $W_1 < W$ be called X then

$$X : C - W = W_1 E : W E_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Now the radius expressed in terms of elasticity (E) is

$$R = \frac{E}{2p\,(C - W)}$$

$$\text{Deflection } \delta = \frac{C - W}{6\,W}$$

The pillar length is $L^2 = 8\,R\,\delta$; hence

$$L^2 = \frac{8\,E}{12\,p\,W} = \frac{2\,E}{3\,p\,W} \text{ and } L_1^2 = \frac{2\,E_1}{3\,p\,W_1}, \text{ and}$$

$$L^2 : L_1^2 = \frac{E}{W} : \frac{E_1}{W_1} = E\,W_1 : E_1\,W \quad \ldots\ldots\ldots\ldots (7)$$

Comparing equations (6) and (7), $X : C - W = L^2 : L_1^2$ where L is the pillar length, and L_1 the length of a pillar of which W_1 is the breaking weight.

Tables Nos. 7 A and 7 B give the X as computed by the above formula for various weights less than the breaking weight, also the respective radii and deflections deduced from the value.

It will be seen that in all cases, whatever the value of W, that $\delta\,R = \delta_1\,R_1 = \delta_{11}\,R_{11} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \delta_n = R_n$

Example.—To find the value of X or pX for a solid 1-in. square cast-iron pillar 9.5 ins. long, of which 48 000 lbs. is the breaking weight, when loaded in the center of resistance with a weight of 24 000 lbs.

The length of a pillar which breaks under a load of 24 000 lbs. is 19.4 diameters $= L_1$, hence $L_1^2 = 376.36$, $C - W = 48\,000$ lbs., and $p\,(C - W) = 29\,400$; hence

$$vX : 29\,400 = 90.25 : 376.36 \text{ and } pX = 7\,050 \text{ and } X = 11\,510.$$

To Find the Radius.—The radius R may be found by the formula—

$$R = \frac{2 - [C_p(W + p(C - W)) + C_p(W - p(C - W))]}{2[C_p(W + p(C - W)) - C_p(W - p(C - W))]}$$

by substituting $W_1 = 24\,000$ lbs. for W and $7\,050 = pX$ for $p(C - W)$.

$$R_1 = \frac{2 - (C_p(24\,000 + 7\,050) + C_p(24\,000 - 7\,050)}{2(C_p(24\,000 - 7\,050) - C_p(24\,000 - 7\,050)}$$

$$R_1 = \frac{2 - (C_p\,16\,950 + C_p\,31\,050)}{2(C_p\,31\,050 - C_p\,16\,950)}$$

$$R_1 = \frac{2 - (0.002897 + 0.001451)}{2(0.002897 - 0.001451)} = 690.1.$$

To Find the Deflection.—The breaking radius of a pillar 9.5 ins. in length as previously described is $R = 67.7$, and the breaking deflection $\delta = 0.16666$, hence $\delta\,R = 11.3$ and $\frac{R\delta}{R_1} = \frac{11.3}{690.1} = 0.01637$, the deflection due to the weight $W_1 = 24\,000$ lbs.

The deflection may be computed however from the quantity pX without reference to the radius by the formula $\delta_1 : \delta = C_1 : C$, where C_1 is the difference of compression between that of the intrados and extrados, and C is the compression of $W + p(C - W) - (W - v(C - W))$, hence

$$\delta_1 = \frac{\delta\,C_p(W_1 + pX) + C_p(W_1 - pX)}{C_p(W + p(C - W)) - C_p(W - p(C - W))},$$

In this case $W + pX = 24\,000 + 7\,050 = 31\,050.$

and $W_1 - pX = 24\,000 - 7\,050 = 16\,950.$

By Table No. 1, compression of $31\,050 = 0.002897$

" " $16\,950 = 0.001450$

and the difference between them $= 0.001447$

By Table No. 1 may also be found

$$C_p(W + p(C - W)) - C_p(W - p(C - W)) =$$
$$0.016683 - 0.001606 = 0.014977$$

and as $\delta = \frac{1}{6}$, hence $\delta_1 = \frac{1 \times 0.001447}{6 \times 0.014977} = 0.0161$

The difference (0.00027) between this result and the previous one is owing to the fact that pillar lengths are developed only to the extent of one decimal, which is ordinarily quite sufficient for all practical purposes.

Table No. 7 A gives the values of $\frac{L^2}{L_1^2}$, of X and pX, the radii and

deflections of various weights less than the breaking weight of a solid square cast-iron pillar 9.5 in length.

Table No. 7 A shows the deflection of the

Breaking	weight,	$W = 48\ 000$ lbs.	to be	0.16666
"	"	$W_1 = 39\ 070$ lbs.	"	0.08333
"	"	$W_1 = 24\ 000$ lbs.	"	0.01655
"	"	$W_1 = 12\ 000$ lbs.	"	0.00528
"	"	$W_1 = 4\ 000$ lbs.	"	0.00155

Table No. 7 B gives the same data for a square solid wrought-iron pillar 19.6 diameters in length.

The deflection under loads less than the breaking load may also be computed directly from the resistance at the breaking point of the pillar $\frac{C - W}{6}$ as follows:

Resistance to bending under lesser weights than the breaking weight, as previously shown, is $X = (C - W)\frac{L^2}{L_1^2}$,

where L is the pillar length in question and L_1 is the breaking length of a pillar which breaks under W_1, the weight assumed as $W_1 < W$.

Let w be a force applied transversely upon the pillar at its middle, then $\frac{x}{6} = \frac{w\,L}{4}$ and $w = \frac{2\,X}{3\,L} = \frac{2}{3}\;\frac{(C - W)\,L^2}{L_1^2\,L} = \frac{2}{3}\;\frac{(C - W)\,L}{L_1^2}$ ..... (8)

If w is considered as a transverse load at the middle of the pillar, and the pillar is considered as a beam resting at the top and bottom, its deflection is $\delta_1 = \frac{w\ L^3}{48\ I\ E}$, and if the pillar as heretofore is solid and 1 in. square, I (mom. inertia) $= \frac{1}{12}$ and $\delta_1 = \frac{w\ L^3}{4\,E}$ .... (9)

Substituting the value of w from equation (8)

$$\delta_1 = \frac{2}{3}\;\frac{(C - W)\,L^4}{4\,E\,L_1^2} = \frac{(C - W)\,L^4}{6\,E\,L_1^2}$$

Example.—Given the solid 1-in. square wrought-iron pillar 19.6 ins. in length, the breaking load of which is $W = 26\ 000$ lbs.; its breaking deflection $\delta = 0.16666$; resistance to crushing, $C = 52\ 000$ lbs.; hence, $C - W = 26\ 000$ lbs.; what is the deflection of this pillar when bending under a load of 12 000 lbs.?

The length of a pillar L_1 that breaks under 12 000 lbs. is 38.8 diameters, and $L_1^2 = 1\ 505.44$.

L being 19.6, hence $L^4 = 14757.9$. The average compression of wrought iron within the limit of elasticity is 0.000045 per 1 000 lbs., hence $E = 22\,220\,000$ and $\delta_1 = \frac{(C - W)\, L^4}{6\, E\, L_1^2} = \frac{26\,000 \times 14\,757.9}{6 \times 22\,220\,000 \times 1\,505.44} =$ 0.019. Table No. 7 B gives 0.01828.

Deflections of safe loads may also, within the limit of elasticity, be derived directly from the breaking deflection by the following method:

$$\text{If } \delta_1 = \frac{(C - W)\, L^4}{6\, E\, L_1^2} \text{ then } \delta = \frac{(C - W)\, L^4}{6\, E_1\, L^2} = \frac{(C - W)\, L^2}{6\, E_1} \text{ and}$$

$$\delta_1 : \delta = \frac{(C - W)\, L^4}{6\, E\, L_1^2} : \frac{(C - W)\, L^2}{6\, E_1} = \frac{L^2}{E} : \frac{L_1^2}{E_1}$$

Approximately the modulus of elasticity of the last 1 000 lbs. of W is to the modulus of elasticity of the last 1 000 lbs. of W_1 as $E : E_1$.

Fig. 10 explains the reason for this statement. Let $a\ b\ c\ d$ be the trapezoid which represents the resistance at the middle of the pillar to vertical load and to bending; then $f\,g$ is the bending force and the triangles $a\,m\,g$ and $n\,g\,d$ represent the resistance to bending, and $a\ m$ and $n\ d$ express a number of pounds, and m and n the mean of this number of pounds. Hence the average of the thousands of pounds located between d and a is to be found at n, and the modulus of elasticity of the 1 000 lbs. at n is also approximately the average of the moduli of the various thousands of pounds contained between d and a. This is approximately but not absolutely true, but the error involved is small and on the safe side.

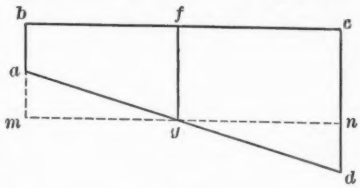


Fig. 10.

Now if the last 1 000 lbs. of $n = (W)\ 1\,000$, and of $m_1 = (W_1)\ 1\,000$, then $E = \frac{(W)\ 1\,000}{C_p\ 1\,000}$ and $E_1 = \frac{W_1\ 1\,000}{C_p\ 1\,000}$ and $\delta_1 : \delta = L^2\ (C_p\, W_1) \frac{1\,000}{C_p\, 1\,000} : L_1^2\ (C_p\ W) \frac{1\,000}{C_p\, 1\,000}$ and $\delta_1 = \delta\ \frac{L^2}{L_1^2}\ \frac{C_p\ 1\,000}{C_p\ 1\,000}\ \frac{(W_1)}{(W)}$

Example.—What is the deflection caused by a weight of 12 000 lbs. upon a solid 1-in. square wrought-iron pillar 19.6 ins. long? $W =$ 26 000 lbs. and $C_p\ (W)\ 1\,000 = 0.00007_1$ $L^2 = 374.16$; $L_1^2 = 1\,505.44$; $C_p\ (W)\ 1\,000 = 0.00004$; $\delta = \frac{1}{6}$; hence $\delta_1 = \frac{1}{6}\ \frac{374.16}{1505.44}\ \frac{4}{7} = 0.02367$.

Table No. 7 gives a deflection of 0.01828, hence the safe load given in Table No. 9, being 10 720 lbs., would be reduced by 388 lbs.

What is the deflection caused by 16 000 lbs. upon a solid cast-iron pillar 9.5 ins. long and 1 in. square as heretofore described? The breaking weight is 48 000 lbs. and the compression due to the last 1 000 lbs., as given in Table No. 1, column 3, is 0.00025. That of the last 1 000 lbs. of 16 000 lbs. is 0.000083, $L^2 = 90.25$ and $L_1^2 = 696.96$. The breaking deflection $\delta = \frac{1}{6}$ hence

$$\delta_1 = \frac{\delta\, L^2\, C_p\, W_1\, 1\,000}{L_1^2\, C_p\, W\, 1\,000} = \frac{1 \times 90.25 \times 0.000083}{6 \times 696.96 \times 0.000250} = 0.00835$$

which exceeds the deflection given in Table No. 7 (0.00800) by 0.00035, hence the safe load is reduced by 33.6 lbs.

An experimental test taken from the reports of the Watertown Arsenal confirms the correctness of deflections δ_1 of weights less than the breaking weight. The report of the Watertown Arsenal of 1888–89 gives on page 733 the deflections of a round hollow cast-iron pillar of 6.35 ins. outer and 4.24 ins. inner diameter under various loads when compressed in the testing machine. It ultimately failed by triple flexure. The length of the pillar is 13.09 or 25.3 diameters, hence the pillar considered as hinged at the ends which corresponds with it is 12.65 diameters long. The radius of gyration of this pillar expressed in terms of the diameter is found to be 0.030236 (in inches, 1.92), hence the length in terms of the radius of gyration is 40.9. Table No. 8 gives the safe load of 14 380 lbs. for this length. The deflection of a pillar 11.8 diameters long (which length in diameters, as given in Table No. 8, corresponds with a length in radius of gyration of 40.9) caused by a load of 14 380 lbs., may be computed by the formula $X : (C - W) = L^2 : L_1^2$ where L is the length of a pillar which has a breaking weight of 14 380 lbs. and which will be found by Table No. 1 to be 29.1; hence X : 54 000* = 139.24 : 846.8 when $X = 8\,877$ lbs. and $pX = 5\,437$. Hence the radius of the pillar in question 11.8 diameters long bent by a load of 14 380 lbs. is 1 011 ins. and $\frac{L^2}{8\,R} = \delta_1 = \frac{139.24}{8\,088} = 0.0172.$

The metal area of the pillar reported by the Watertown Arsenal is 17.28 sq. ins., hence the total load of the pillar corresponding to the safe load 14 380 lbs. is 248 486 lbs. The report gives deflections at the

* Breaking weight of a pillar 11.8 diameters long is $W = 38\,000$ lbs.
$T = 16\,000$ "
$W + T = 54\,000$ lbs.

middle of the pillar in two directions, horizontal and vertical, for 240 000 lbs., of 0.04 and 0.06 in., respectively, and for 260 000 lbs., of 0.05 and 0.07 in. From this data may be deduced the deflection of 248 436 lbs. as 0.056 and 0.084 in. The true deflection the resultant of the vertical and horizontal deflections is $\delta_1 = \sqrt{0.056^2 + 0.084^2} = 0.101$. Divide this by the diameter of the pillar, 6.35, and it will be found that the deflection $\delta_1 = 0.016$.

Table No. 7 A gives the radii and deflections pertaining to various weights (W_1) from nil to 48 000 lbs., which is the breaking weight of a solid 1-in. square cast-iron pillar 9.5 ins. in length.

Table No. 7 B gives the radii and deflections pertaining to various weights (W) from nil to 26 000 lbs., which is the breaking weight of a solid 1-in. square wrought-iron pillar 19.6 ins. long.

If it is intended that the maximum strain of the pillar shall not exceed 16 000 lbs., one-sixth of the ultimate strength of the material, and that no load bending the pillar can be considered to be a safe load which results in a maximum strain greater than 16 000 lbs., it is clear that a load of 15 232 lbs. would certainly constitute a safe load, inasmuch as the resistance to the bending moment does not exceed 768 lbs. In fact, the deflection caused by a weight of 15 232 lbs. is less than 0.008, hence the bending moment is less than 128 lbs. It will be seen by Table No. 8 that the safe load for the pillar described previously is 15 300 lbs.

Table No. 8 has been computed in the manner indicated. A load W_1 is assumed as probable to constitute a safe load of a given pillar, and its deflection is computed by the method given on page 137; then the correctness of the assumed load is tested by the formula $W_1 + 6\delta_1 W_1 = MS$, wherein MS means the maximum strain at the intrados. If $MS > 16\,000$ lbs., then W_1 must be smaller than the W_1 first assumed, and if $MS < 16\,000$ lbs., then W_1 is greater. Column 1 in Table No. 8 gives the lengths of pillars expressed in diameters, and column 2 in terms of the radius of gyration, for convenient reference in computing safe loads for pillars of all forms. Column 3 gives the safe loads, and column 4 the respective breaking loads.

It will be noticed that for pillars less than seven diameters in length the safe load is one-fourth the breaking load, and less when the pillar is very short. From seven to about twelve diameters in length, the safe load varies from one-fourth to one-third of the breaking load. From

12 to 25 diameters the safe load varies from one-third to one-half the breaking load, and from 25 to 50 diameters the safe load is nearly one-half the breaking load. The significance of the relation of safe loads to breaking loads becomes more apparent by reversing the above statement as follows :

Breaking loads approximate safe loads (which cause a given maximum strain) in magnitude in a ratio related to the length of the pillar.

With a pillar of infinite length the safe load and the breaking weight must both be nil, and with a pillar of inappreciable length, say, a thin plate, the safe load multiplied by the factor of safety is equal to the breaking weight.

Table No. 9 gives for wrought-iron pillars all the data contained in Table No. 8 for cast-iron pillars.

Example.—Find from Table No. 8 the safe load per inch of metal of a round, hollow cast-iron column 20 ft. long and 12 ins. outer and 10 ins. inner diameter.

The radius of gyration is $R_g = \sqrt{\frac{D^2 + d^2}{16}} = \sqrt{\frac{144 + 100}{16}} = \frac{17}{4} =$ 4.25 ins. The length of the pillar in inches is $20 \times 12 = 240$ and length in terms of the radius of gyration is $L_g = 56.5$. Table No. 8 gives the safe load per inch of metal of a pillar 56.5 radii of gyration in length as 12 000 lbs.

It may be noted here that cast-iron pillars not exceeding 28 diameters or 97 radii of gyration in length are not subject to tension at the extrados under a safe load, as given in Table No. 8, when the load is placed in the center of gravity of the pillar. Inequalities and other probable defects of castings are assumed to be covered by the factor of safety.

Breaking loads for cast-iron pillars as given in Table No. 1 and for wrought-iron pillars as given in Table No. 2, also the respective safe loads, as given in Tables Nos. 8 and 9, being computed on the assumption that the load is applied in the center of gravity of the pillar, it is essential that this should be the case accurately, inasmuch as slight deviations cause material differences in their magnitude. A cast-iron pillar 10 ins. in diameter and 11.9 ft. in length ($L = 14.3$) will break under a load of 32 000 lbs. per inch metal area, when the load is placed in the center of gravity of the pillar. When placed 1 in. to one side of the center it will break under 21 150 lbs., and when placed 0.5 in. off the center of gravity of the pillar the breaking load is 26 050 lbs. or 19% less than when exactly in the center.

Brickwork.

The report of tests of the strength of structural material made at the Watertown Arsenal during the year 1884 gives on page 92 the compression of a common hard-brick pier, 8 ins. square and 16.48 ins. high, laid in lime mortar composed of 1 part lime and 3 parts sand, 15 months old when tested.

If brickwork laid up with good cement (say, 1 part of the best Rosendale and 2½ parts of sand) is used in ordinary building, at least six months expire before it is loaded to the full extent of the safe load assumed. The resistance to compression of brickwork so laid may be considered fully as great as that of brickwork laid up in lime mortar 15 months old. Its compressibility will probably be less. It is doubtless safe to assume that it is no greater.

Table No. 10 gives compression in parts of 1 for loads up to 2 000 lbs. per square inch, as deduced from the Watertown experiments, and shows a sufficient uniformity to warrant the acceptance of a modulus of elasticity of 160 000 without appreciable error in practice.

Let 2 000 lbs. be the breaking weight (it is 2 440 lbs. in the Watertown test) and 300 lbs. the maximum stress permissible under a safe load, also let the cohesion of the cement mortar be ignored as a medium of resistance to tension, then one-sixth the diameter becomes the greatest possible deflection at the breaking point. In other words, the breaking point occurs whenever the stress at the intrados amounts to 2 000 lbs. or the stress at the extrados is nil.

With uniform elasticity the radius $R = \frac{E}{2\,p\,(C - W)}$ and as $\delta = \frac{C - W}{6\,W}$ and $L^2 = 8\,\delta\,R$, hence, $L^2 = \frac{2\,E}{3\,p\,W}$ and as $E = 160\,000$, then $L^2 = \frac{174\,000}{W}$ and $W = \frac{174\,000}{L^2}$.

The stress at the intrados under a safe load is 300 lbs. up to a pillar length of 13.2 diameters, where the breaking load is 1 000 lbs. In pillars of greater lengths the stress at the intrados cannot exceed twice the amount of the safe load without causing tension at the extrados.

For lengths in terms of the diameters, L, the square of the respective lengths, L^2, breaking loads per square inch of sectional area, breaking deflections, safe loads per inch area and deflections under them, see Table No. 11.

It will be noticed that for lengths greater than 13.2 diameters the deflection of safe loads is intended to remain constant.

The weights of floors supported in the center of resistance of a wall or pier constitute a part of the superincumbent weight, pound for pound. It frequently happens, however, that floor beams or girders are so placed that they constitute an eccentric load, and if n be the eccentricity, such floor loads should be multiplied by $(6\,n + 1)$ in order to ascertain the value of the centric load which represents them. This rule is approximately correct in view of the minute deflections under safe loads as applied in practical building.

Yellow Pine Pillars.

Table No. 12 gives the safe loads for yellow pine pillars based upon $E = 1\,600\,000$, computed as described previously.

For knots and sap due allowance is to be made, and 25% may be added for pillars for temporary use.

Summary.

For convenience in use, the leading formulas deduced in the preceding discussion are printed here, together with the notation.

Notation.—C is the ultimate resistance of the material to compression.

T is the ultimate resistance of the material to tension.

W " breaking weight.

W_1 is a weight less than the breaking weight.

δ is the breaking deflection.

δ_1 " deflection caused by W_1.

R " radius at the breaking point.

R_1 " " with the load W_1.

L " length of the pillar in terms of the diameter.

d " diameter, taken as 1 in the paper. Hence the moment of inertia I_1 is $\frac{1}{12}$ for a solid square section, and the moment of resistance is $\frac{1}{6}$.

C_p is the amount of compression.

R_g " radius of gyration.

p " coefficient 0.6125.

E_c is the modulus of elasticity for compression.
E_t " " " tension.
n " eccentricity, expressed by a fraction of the diameter.
x and y are the coefficients of stress in eccentric loads.

Formulas.—Breaking weights and safe loads are computed upon the assumption that pillars are compressed in the center of resistance and are subject to single flexure, except in the case of eccentric loading.

1. Deflection at the breaking point.

$$\delta = \frac{C-W}{6\,W}$$

2. Radius at the breaking point corresponding to given deflections.

$$R = \frac{2-(C_p\,(W+p\,(C-W))+C_p\,(W-p\,(C-W)))}{2\,(C_p\,\,(W+p\,(C-W))-C_p\,(W-p\,(C-W)))}$$

3. Breaking length.

$$L = \sqrt{8\,\delta\,R}$$

With eccentric loading.

4. Compression at the ends of the pillar.

$$x = 6\,n+1 \qquad y = 6\,n-1.$$

5. Breaking weight expressed in ultimate resistance of the material and centric breaking loads.

$$W_1 = \pm\sqrt{\left(\frac{C+W+6\,n\,W}{1}\right)^2 - C\,W} + \left(\frac{C+W+6\,n\,W}{2}\right)$$

$$W_1 = \pm\sqrt{\left(\frac{W-6\,n\,W-T}{2}\right)^2 + T\,W} + \left(\frac{W-6\,n\,W-T}{2}\right)$$

6. Resistance, to bending when W_1 is less than W.

$$x = (C-W)\frac{L^2}{L_1^2}$$

7. Deflection, when W_1 is less than W.

$$\delta_1 = \frac{(C-W)\,L^4}{6\,E\,L_1^2} \text{ or } \delta_1 = \delta\,\frac{L^2\,C_p\,1\,000\,(W_1)}{L_1^2\,C_p\,1\,000\,(W)}$$

8. Brickwork.

$$E = 160\,000. \quad W = \frac{2\,E}{3\,p\,L^2} = \frac{174\,000}{L^2} \quad R = \frac{E}{2\,p\,(C-W)} = \frac{130\,60\,0}{C-W}.$$

9. Yellow pine posts.

$$E = 1\,600\,000 \qquad W_1 = \frac{1\,740\,000}{L^2} \qquad R = \frac{1\,306\,000}{C-W}.$$

TABLE No. 1.—Breaking Weights for Round-Ended Solid 1-In. Square Cast-Iron Pillars, Loaded in the Center.

Breaking weight, W.	Compression due to W.	Compression due to the last 1 000 pounds.	Strain at the middle of the column. Compression, —; Tension, +	Deflection, δ.	Average strain at the intrados, $W + p\,(C - W)$.	Average strain at the extrados, $W - p\,(C - W)$.	Radius, R.	Length, L.
96 000	0.026000	....	—96 000	....	96 000	96 000	....	......
95 000	0.025333	0.000667	—94 000	0.00175	95 612	94 388	1 259.2	4.2
94 000	0.024736	0.000597	—92 000	0.00345	95 223	92 775	670.2	4.2
93 000	0.024155	0.000581	—90 000	0.00537	94 837	91 163	462.9	4.4
92 000	0.023590	0.000565	—88 000	0.00724	94 449	89 551	354.6	4.4
91 000	0.023038	0.000552	—86 000	0.00916	94 062	87 938	288.8	4.5
90 000	0.022493	0.000545	—84 000	0.01111	93 675	85 325	244.2	4.6
89 000	0.021955	0.000538	—82 000	0.01311	93 287	84 713	213.2	4.7
88 000	0.021424	0.000531	—80 000	0.01515	92 900	83 100	189.1	4.8
87 000	0.020900	0.000524	—78 000	0.01724	92 512	81 488	170.5	4.8
86 000	0.020383	0.000517	—76 000	0.01938	92 125	79 875	155.7	4.9
85 000	0.019873	0.000510	—74 000	0.02157	91 737	78 263	143.7	4.9
84 000	0.019370	0.000503	—72 000	0.02381	91 350	76 650	133.5	5.0
83 000	0.018874	0.000496	—70 000	0.02610	90 962	75 038	125.1	5.1
82 000	0.018385	0.000489	—68 000	0.02846	90 575	73 425	117.8	5.1
81 000	0.017903	0.000482	—66 000	0.03086	90 187	71 813	111.6	5.2
80 000	0.017428	0.000475	—64 000	0.03333	89 800	70 200	106.3	5.3
79 000	0.016960	0.000468	—62 000	0.03797	89 412	68 588	101.5	5.5
78 000	0.016499	0.000461	—60 000	0.04060	89 025	66 975	97.9	5.6
77 000	0.016045	0.000454	—58 000	0.04113	88 637	65 363	93.8	5.6
76 000	0.015598	0.000447	—56 000	0.04386	88 250	63 756	90.6	5.6
75 000	0.015158	0.000440	—54 000	0.04666	87 862	62 138	87.7	5.7
74 000	0.014725	0.000433	—52 000	0.05000	87 475	60 525	85.1	5.8
73 000	0.014299	0.000426	—50 000	0.05251	87 087	58 913	82.3	5.9
72 000	0.013880	0.000419	—48 000	0.05585	86 700	57 300	80.7	6.0
71 000	0.013468	0.000412	—46 000	0.05879	86 312	55 688	78.8	6.2
70 000	0.013063	0.000405	—44 000	0.06190	85 855	54 145	77.5	6.2
69 000	0.012665	0.000398	—42 000	0.06522	85 537	52 463	75.6	6.2
68 000	0.012274	0.000391	—40 000	0.06872	85 150	50 850	74.3	6.2
67 000	0.011890	0.000384	—38 000	0.07211	84 762	49 238	73.1	6.4
66 000	0.011513	0.000377	—36 000	0.07575	84 375	47 625	72.0	6.6
65 000	0.011143	0.000370	—34 000	0.07949	83 987	46 013	71.0	6.7
64 000	0.010718	0.000362	—32 000	0.08333	83 600	44 400	70.2	6.8
63 000	0.010426	0.000355	—30 000	0.08730	83 212	42 788	69.5	6.9
62 000	0.010078	0.000348	—28 000	0.09140	82 825	41 175	68.9	7.0
61 000	0.009737	0.000341	—26 000	0.09590	82 437	39 563	68.4	7.2
60 000	0.009403	0.000334	—24 000	0.10000	82 050	37 950	68.1	7.3
59 000	0.009076	0.000327	—22 000	0.10482	81 662	36 338	67.6	7.5
58 000	0.008756	0.000320	—20 000	0.10920	81 275	34 725	67.5	7.6
57 000	0.008443	0.000313	—18 000	0.11404	80 887	33 113	67.3	7.8
56 000	0.008137	0.000306	—16 000	0.11905	80 500	31 500	67.2	8.0
55 000	0.007838	0.000299	—14 000	0.12406	80 112	29 888	67.2	8.1
54 000	0.007546	0.000293	—12 000	0.13000	79 725	28 275	67.2	8.3
53 000	0.007261	0.000285	—10 000	0.13522	79 337	26 663	67.3	8.5
52 000	0.006983	0.000278	— 8 000	0.14102	78 950	25 050	67.4	8.7
51 000	0.006712	0.000271	— 6 000	0.14706	78 562	23 438	67.4	8.9
50 000	0.006448	0.000264	— 4 000	0.15333	78 175	21 825	67.5	9.1
49 000	0.006191	0.000257	— 2 000	0.15986	77 787	20 213	67.7	9.3
48 000	0.005941	0.000250	0 000	0.16666	77 400	18 600	67.7	9.5
47 000	0.005698	0.000243	+ 2 000	0.17375	77 012	16 988	67.8	9.7
46 000	0.005460	0.000238	+ 4 000	0.18116	76 625	15 375	68.0	9.9
45 000	0.005232	0.000228	+ 6 000	0.18888	76 237	13 763	68.1	10.1
44 000	0.005014	0.000218	+ 8 000	0.19700	75 850	12 150	68.3	10.2
43 000	0.004806	0.000208	+10 000	0.20542	75 462	10 538	68.5	10.6
42 000	0.004608	0.000198	+12 000	0.21429	75 075	8 925	68.6	10.8
41 000	0.004418	0.000190	+14 000	0.22358	74 687	7 313	68.7	11.1
40 000	0.004235	0.000183	+16 000	0.23333	74 300	5 700	68.9	11.3

TABLE No. 1—(*Continued*).

Breaking weight, W.	Compression due to W.	Compression due to the last 1 000 pounds.	Strain at the middle of the column. Compression, $-$ Tension, $+$	Deflection, δ.	Average strain at the intrados, $W + p\,(C - W)$.	Average strain at the extrados, $W - p\,(C - W)$.	Radius, R.	Length, L.
39 000	0.004059	0.000176	*—94 000	0.23500	72 687	5 313	72.2	11.6
38 000	0.003890	0.000169	—92 000	0.23684	71 075	4 925	74.3	11.8
37 000	0.003728	0.000162	—90 000	0.23874	69 462	4 538	79.8	12.3
36 000	0.003533	0.000155	—88 000	0.24074	67 850	4 150	83.7	12.7
35 000	0.003425	0.000148	—86 000	0.24285	66 237	3 763	87.9	13.0
34 000	0.003283	0.000142	—84 000	0.24510	64 625	3 375	93.2	13.5
33 000	0.003147	0.000136	—82 000	0.24747	63 012	2 988	97.6	13.9
32 000	0.003016	0.000131	—80 000	0.25000	61 400	2 600	103.3	14.3
31 000	0.002891	0.000125	—78 000	0.25268	59 787	2 213	109.1	14.8
30 000	0.002771	0.000120	—76 000	0.25555	58 175	1 825	115.3	15.3
29 000	0.002657	0.000114	—74 000	0.25862	56 562	1 438	121.5	15.8
28 000	0.002547	0.000110	—72 000	0.26190	54 950	1 050	128.7	16.4
27 000	0.002441	0.000106	—70 000	0.26543	53 337	663	136.4	17.0
26 000	0.002337	0.000104	—68 000	0.26920	51 725	275	144.7	17.6
25 000	0.002235	0.000102	—66 000	0.27333	50 112	112	153.7	18.3
24 000	0.002134	0.000101	—64 000	0.27777	48 500	500	170.4	19.4
23 000	0.002034	0.000100	—62 000	0.28261	46 887	887	173.8	19.8
22 000	0.001935	0.000099	—60 000	0.28800	45 175	1 175	185.8	20.6
21 000	0.001837	0.000098	—53 000	0.29365	43 662	1 662	196.5	21.5
20 000	0.001740	0.000097	—56 000	0.30000	42 050	2 050	208 9	22.4
19 000	0.001644	0.000096	—54 000	0.30700	40 437	2 437	221.4	23.3
18 000	0.001549	0.000095	—52 000	0.31480	38 825	2 825	234.6	24.3
17 000	0.001455	0.000094	—50 000	0.32335	37 212	3 212	248.5	25.3
16 000	0.001362	0.000093	—48 000	0.33333	35 600	3 600	262.3	26.4
15 000	0.001270	0.000092	—46 000	0.34444	33 987	3 987	276.9	27.6
14 000	0.001179	0.000091	—44 000	0.35715	32 375	4 375	291.7	28.8
13 000	0.001089	0.000090	—42 000	0.37154	30 772	4 772	306.6	30.1
12 000	0.001000	0.000089	—40 000	0.38888	29 150	5 150	322.2	31 8
11 000	0.000912	0.000088	—38 000	0.40909	27 537	5 537	337.8	33.2
10 000	0.000825	0.000087	—36 000	0.43333	25 925	5 925	353.9	35 0
9 000	0.000739	0.000086	—34 000	0.46300	24 312	6 312	371.3	37.0
8 000	0.000654	0.000085	—32 000	0.50000	22 700	6 700	389.7	39.4
7 000	0.000570	0.000084	—30 000	0.54760	21 087	7 087	409.9	42.3
6 000	0.000487	0.000083	—28 000	0.61111	19 775	7 475	425.9	45.6
5 000	0.000404	0.000083	—26 000	0.70000	17 832	7 832	460.8	50.0
4 000	0.000322	0.000082	—24 000	0.83333	16 250	8 250	486.0	56.9
3 000	0.000240	0.000082	—22 000	1.05555	14 637	8 637	521.0	66.3
2 000	0.000195	0.000081	—20 000	1.50000	13 025	9 025	535.7	80.0
1 000	0.000079	0.000080	—18 000	2.83330	11 412	9 412	584.4	115.1

* Strains at this point change from the extrados to the intrados, where heretofore the strain has been 96 000. At the extrados the strain continues at +16 000 to the end of the table.

TABLE No. 2.—Breaking Weights for Round-Ended Solid 1-In. Square Wrought-Iron Pillars, Loaded in the Center.

Breaking weight, *W*.	Compression due to *W*.	Compression due to the last 1 000 pounds.	Strain at the middle of the column. Compression, — Tension, +	Deflection, δ.	Average strain at the extrados.	Average strain at the intrados.	Radius, *R*.	Length, *L*.
52 000	0.00800	....	—52 000	....	—52 000	52 000	....	......
51 000	0.00749	0.00051	—50 000	0.0033	—50 388	51 612	1 654.2	6.6
50 000	0.00701	0.00048	—48 000	0.0066	—48 776	51 224	863.4	6.7
49 000	0.00655	0.00046	—46 000	0.0102	—47 163	50 837	605.7	7.0
48 000	0.00611	0.00044	—44 000	0.0140	—45 550	50 450	473.2	7.4
47 000	0.00569	0.00042	—42 000	0.0177	—43 938	50 062	394.0	7.4
46 000	0.00529	0.00040	—40 000	0.0217	—42 325	49 675	346.5	7.7
45 000	0.00491	0.00038	—38 000	0.0259	—40 713	49 287	313.8	8.0
44 000	0.00455	0.00036	—36 000	0.0303	—39 100	48 900	290.1	8.4
43 000	0.00421	0.00034	—34 000	0.0349	—37 488	48 512	273.3	8.7
42 000	0.00389	0.00032	—32 000	0.0397	—35 875	48 125	261.4	9.1
41 000	0.00359	0.00030	—30 000	9.0447	—34 263	47 737	254.7	9.5
40 000	0.00331	0.00028	—28 000	0.0500	—32 650	47 350	250.0	10.0
39 000	0.00305	0.00026	—26 000	0.0555	—31 038	46 962	250.0	10.5
38 000	0.00281	0.00024	—24 000	0.0614	—29 425	46 575	250.0	11.1
37 000	0.00259	0.00022	—22 000	0.0676	—27 813	46 187	250.0	11.6
36 000	0.00239	0.00020	—20 000	0.0741	—26 200	45 800	250.0	12.1
35 000	0.00221	0.00018	—18 000	0.0810	—24 588	45 412	253.6	12.8
34 000	0.00205	0.00016	—16 000	8.0884	—22 975	45 025	257.6	13.5
33 000	0.00191	0.00014	—14 000	0.0960	—21 363	44 637	261.7	14.1
32 000	0.00178	0.00013	—12 000	0.1042	—19 750	44 250	265.0	14.8
31 000	0.00166	0.00012	—10 000	0.1129	—18 128	43 872	270.4	15.6
30 000	0.00155	0.00011	— 8 000	0.1222	—16 525	43 475	272.1	16.3
29 000	0.00145	0.00010	— 6 000	0.1322	—14 913	43 087	277.8	17.1
28 000	0.00136	0.00009	— 4 000	0.1426	—13 400	42 600	284.2	18.0
27 000	0.00128	0.00008	— 2 000	0.1543	—11 688	42 312	286.0	18.7
26 000	0.00121	0.00007	0 000	0.1666	—10 075	41 925	288.4	19.6
25 000	0.00115	0.00006	+ 2 000	0.1800	— 8 463	41 537	292.6	20.5
24 000	0.00110	0.00005	+ 4 000	0.1944	— 6 850	41 150	295.4	21.4
23 000	0.00105	0.00005	+ 6 000	0.2101	— 5 238	40 762	301.5	22.5
22 000	0.00100	0.00005	+ 8 000	0.2272	— 3 625	40 375	306.2	23.5
21 000	0.00095	0.00005	+10 000	0.2460	— 2 013	39 987	309.0	24.6
20 000	0.00090	0.00005	+12 000	0.2666	— 400	39 600	310.0	25.7
19 000	0.00085	0.00005	+14 000	0.2900	+ 1 212	39 212	318.0	27.1
18 000	0.00080	0.00005	+16 000	0.3148	+ 2 825	38 825	320.0	28.4
17 000	0.00075	0.00005	+18 000	0.3431	+ 4 437	38 437	323.5	29.7
16 000	0.00070	0.00005	+20 000	0.3750	+ 6 050	38 050	326.3	31.3
15 000	0.00065	0.00005	+22 000	0.4111	+ 7 662	37 662	328.0	32.8
14 000	0.00060	0 00005	+24 000	0.4524	+ 9 275	37 275	329.6	34.5
13 000	0.00055	0.00005	+26 000	0.5000	+10 887	36 887	331.8	36.4
12 000	0.00050	0.00004	+28 000	0.5555	+12 500	36 500	332.0	38.4
11 000	0.00046	0.00004	+30 000	0.6212	+14 112	36 112	329.9	40.5
10 000	0.00041	0.00004	+32 000	0.7000	+15 725	35 725	329.7	42.9
9 000	0.00037	0.00004	+34 000	0.8000	+17 337	35 337	327.6	45.7
8 000	0.00032	0.00004	+36 000	0.9166	+18 950	34 950	326.6	48.9
7 000	0.00028	0.00004	+38 000	1.0714	+20 562	34 562	325.5	52.8
6 000	0.00024	0.00004	+40 000	1.2777	+22 175	34 175	323.5	57.5
5 000	0.00020	0.00004	+42 000	1 5666	+23 778	33 778	322.4	63.5
4 000	0.00016	0.00004	+44 000	2.0000	+25 400	33 400	318.3	71.3
3 000	0.00012	0.00004	+46 000	2.7222	+27 010	33 010	313.4	82.5
2 000	0.00008	0.00004	+48 000	4.1666	+28 625	32 625	304.8	100.7
1 000	0.00004	0.00004	+50 000	8.5000	+30 240	32 240	295.0	141.6
500	0.00002	0.00004	+51 000	17.1666	+32 040	33 040	280.9	196.4

TABLE No. 3.—Breaking Loads of Round-Ended Solid 1-In. Square Cast-Iron Pillars, Loaded in the Center.

Compression, — Tension, +

Breaking weight, W.	Strains at the middle of the pillar at extrados to *, afterward at intrados.	Deflection, δ.	Average strain at the intrados. $W + p\,(C - W)$.	Average strain at the extrados, $W - p\,(C - W)$.	Radius, R.	Length, L.
96 000	−96 000	....	....	....	....	....
95 000	−94 000	0.0020	95 635	94 365	1 230.8	4.0
94 000	−92 000	0.0040	95 273	92 727	643.7	4.4
93 000	−90 000	0.0064	94 909	91 091	455.5	4.8
92 000	−88 000	0.0088	94 545	89 455	349.1	4.9
91 000	−86 000	0.0104	94 182	87 818	268.6	4.8
90 000	−84 000	0.0124	93 675	86 275	243.1	4.8
89 000	−81 630	0.0144	93 287	84 486	....	....
88 000	−79 250	0.0168	92 900	82 640	....	....
87 000	−76 730	0.0184	92 512	80 710	....	....
86 000	−74 300	0.0200	92 125	78 834	....	....
85 000	−72 150	0.0220	91 737	77 130	133.5	4.8
84 000	−70 000	0.0240	91 350	75 425	....	....
83 000	−67 500	0.0265	90 962	73 510	....	....
82 000	−65 000	0.0290	90 575	71 590	....	....
81 000	−62 500	0.0305	90 187	69 670	....	....
80 000	−60 000	0.0324	89 800	67 750	96.4	5.0
79 000	−57 500	0.0344	89 412	65 220	....	....
78 000	−55 000	0.0368	89 075	63 910	....	....
77 000	−52 500	0.0400	88 640	62 000	....	....
76 000	−50 000	0.0432	88 250	60 075	81.2	5.3
75 000	−46 800	0.0480	87 826	57 730	77.8	5.4
74 000	−43 500	0.0528	87 475	54 700	73.5	5.5
73 000	−39 500	0.0580	87 090	52 480	71.3	5.7
72 000	−35 000	0.0632	86 700	49 338	....	....
71 000	−30 400	0.0697	86 312	46 133	65.9	6.0
70 000	−25 300	0.0752	85 925	42 620	....	....
69 000	−19 700	0.0826	85 537	38 800	61.2	6.3
68 000	−14 000	0.0900	85 150	34 925	59.8	6.5
67 000	−10 000	0.0975	84 762	32 090	....	....
66 000	− 6 000	0.1000	84 375	29 250	....	....
65 000	− 2 200	0.1054	83 987	26 535	58.6	7.0
64 000	+ 1 000	0.1104	83 600	24 190	58.1	7.1
63 000	+ 4 500	0.1144	83 170	21 660	58.0	7.2
62 000	+ 8 000	0.1184	82 825	19 125	....	....
61 000	+11 500	0.1224	82 437	16 590	57.7	7.5
60 000	+15 000	0.1264	82 050	14 063	57.5	7.6
59 000	+16 000	0.1304	81 540	13 060	....	....
	*				....	....
58 000	−94 600	0.1344	80 420	12 675	....	....
57 000	−93 290	0.1372	79 230	12 290	58.5	8.0
56 000	−91 975	0.1400	78 035	11 900	63.8	8.4
55 000	−90 670	0.1432	76 850	11 510	66.0	8.7
54 000	−89 350	0.1464	75 650	11 125	68.3	8.9
53 000	−88 040	0.1492	74 460	10 740	70.6	9.1
52 000	−86 725	0.1520	73 270	10 350	71.6	9.3
51 000	−85 420	0.1540	72 080	9 960	75.7	9.6
50 000	−84 100	0·1560	70 890	9 575	79.0	9.9
49 000	−82 640	0.1572	69 500	9 190	82.1	....
48 000	−81 175	0.1584	68 320	8 800	85.1	10.0
47 000	−80 020	0.1608	67 225	8 410	88.0	10.6
46 000	−78 850	0.1632	66 120	8 025	91.1	10.9
45 000	−77 540	0.1652	64 930	7 640	95.3	11.2
44 000	−76 225	0.1672	63 740	7 250	99.3	11.5
43 000	−74 920	0.1676	62 550	6 860	102.4	11.7

TABLE No. 3—(*Continued*).

Breaking weight, W.	Strains at the middle of the pillar at extrados to*, afterward at intrados.	Deflection, δ.	Average strain at the intrados, $W + p\,(C - W)$.	Average strain at the extrados, $W - p\,(C - W)$.	Radius, R.	Length, L.
42 000	—73 600	0.1680	61 350	6 475	106.5	11.9
41 000	—72 290	0.1692	60 165	6 090	112.1	12.3
40 000	—70 975	0.1704	58 970	5 700	115.7	12.5
39 000	—69 700	0.1720	57 800	5 310	120.5	12.8
38 000	—68 350	0.1736	56 590	4 925	125.7	13.2
37 000	—66 040	0.1760	54 790	4 540	134.4	13.8
36 000	—65 725	0.1784	54 200	4 150	137.0	14.0
35 000	—64 420	0.1808	53 020	3 760	143.0	14.4
34 000	—63 100	0.1824	51 820	3 375	149.5	14.7
33 000	—61 790	0.1856	50 630	2 990	156.1	15.2
32 000	—60 475	0.1888	49 440	2 600	164.4	15.5
31 000	—59 170	0.1928	48 250	2 210	172.1	16.4
30 000	—57 850	0.1968	47 060	1 825	179.1	16.8
29 000	—56 540	0.2004	45 970	1 440	187.0	17.0
28 000	—55 230	0.2044	44 730	1 050	196.2	17.8
27 000	—53 920	0.2084	43 490	660	205.4	18.5
26 000	—52 600	0·2128	42 290	375	215.1	19.1
25 000	—51 300	0.2192	41 110	112	224.4	19.8
24 000	—50 000	0.2256	39 920	500	234.2	20.5
23 000	—48 500	0.2336	38 620	890	245.2	21.4
22 000	—47 000	0.2416	37 090	1 275	260.0	22.4
21 000	—46 000	0.2504	36 310	1 660	269.0	23.2
20 000	—45 000	0.2592	35 310	2 050	275.0	23.9
19 000	—44 250	0.2708	34 460	2 470	282.3	24.7
18 000	—43 500	0.2824	33 620	2 825	290.5	25.6
17 000	—42 550	0.2980	32 650	3 210	298.2	26.6
16 000	—41 600	0.3136	31 680	3 600	306.9	27.7
15 000	—40 800	0.3316	30 800	3 990	312.9	28.8
14 000	—40 000	0.3496	29 910	4 375	320.4	29.9
13 000	—39 000	0.3724	28 910	4 762	329.4	31.3
12 000	—38 000	0.3953	27 910	5 150	338.4	32.7
11 000	—36 650	0.4320	26 710	5 540	350.2	34.8
10 000	—35 300	0.4688	25 500	5 925	362.5	36.9
9 000	—33 650	0.5128	24 100	6 310	374.4	39.9
8 000	—32 000	0.5568	22 700	6 700	390.6	41.7
7 000	—30 150	0.6160	21 180	7 090	410.1	44.9
6 000	—28 300	0.6752	19 660	7 475	431.3	48.2
5 000	—26 650	0.7504	18 260	7 860	448.7	51.9
4 000	—25 000	0.8256	16 860	8 259	473.5	55.9

TABLE No. 4.—BREAKING WEIGHTS OF ROUND-ENDED SOLID 1-IN. SQUARE WROUGHT-IRON PILLARS, LOADED IN THE CENTER.

Compression, — Tension, +

Breaking weight, W.	Strains at the middle of the pillar.	Deflection, δ.	Average strain at the intrados, $W + p(C - W)$.	Average strain at the extrados, $W - p(C - W)$.	Radius, R.	Length, L.
52 000	52 000					
51 000	49 900	0.0040	51 610	50 330	1 600.8	7.1
50 000	47 800	0.0080	51 225	48 650	827.5	7.2
49 000	45 500	0.0120	50 840	46 860	558.1	7.3
48 000	43 000	0.0160	50 450	44 940	424.7	7.3
47 000	40 600	0.0208	50 030	42 960	351.4	7.6
46 000	38 200	0.0256	49 675	41 220	310.3	7.7
45 000	36 100	0.0304	49 290	39 550	285.2	8.3
44 000	34 000	0.0352	48 900	37 875	268.3	8.6
43 000	31 500	0.0428	48 512	35 960	252.0	9.2
42 000	28 000	0.0504	48 125	33 425	337.7	9.7
41 000	25 000	0.0600	47 740	31 200	230.6	10.5
40 000	20 500	0.0696	47 350	28 160	222.9	11.1
39 000	15 000	0.0788	46 960	24 300	218.8	11.7
38 000	4 000	0.0890	46 575	12 275	199.0	11.8
37 000	12 000	0.0996	46 190	6 999	195.9	12.2
36 000	16 000	0.1112	45 800	4 150	197.7	13.2
35 000	19 600	0.1228	45 410	1 430	199.5	14.0
34 000	22 000	0.1344	45 025	300	202.4	14.7
33 000	24 000	0.1488	44 640	2 910	204.4	14.7
32 000	25 500	0.1632	44 250	3 220	210.0	16.5
31 000	27 000	0.1812	43 860	4 525	213.8	17.6
30 000	28 000	0.1992	43 475	5 525	218.8	18.6
29 000	29 400	0.2164	43 090	6 770	226.3	19.7
28 000	30 000	0.2336	42 700	7 525	227.8	20.6
27 000	31 000	0.2522	42 310	8 525	232.1	21.6
26 000	31 500	0.2708	41 925	9 220	237.7	22.7
25 000	31 750	0.2952	41 540	9 760	248.6	24.0
24 000	32 000	0.3169	41 150	10 300	249.3	25.1
23 000	32 250	0.3440	40 760	10 840	255.3	26.5
22 000	32 500	0.3684	40 375	11 380	261 3	27.7
21 000	33 000	0.3932	39 990	12 075	267.0	28.9
20 000	33 500	0.4180	39 600	12 770	271.3	30.1
19 000	33 750	0.4462	39 210	13 310	279 7	31.6
18 000	34 000	0.4744	38 825	13 850	285.3	32.9
17 000	34 500	0.5299	38 440	14 240	292.2	35.1
16 000	35 000	0.5855	38 050	15 240	297.3	37.3
15 000	35 500	0.6419	37 660	15 930	302.7	39.4
14 000	36 000	0.6983	37 275	16 625	308.3	41.5
13 000	36 500	0.7503	36 890	17 320	311.0	43.2
12 000	37 000	0.8023	36 500	18 010	319.2	45.2
11 000	37 500	0.8934	36 110	18 700	325.4	48.2
10 000	38 000	0.9846	35 725	19 400	330.0	50.9
9 000	38 300	1.0374	35 340	19 970	334.2	52.6
8 000	38 600	1.0902	34 950	20 540	340.0	54.4
7 000	39 300	1.3979	34 560	21 360	343.4	62.0
6 000	40 000	1.7056	34 175	22 175	346.2	68 7
5 000	40 750	2.2910	33 790	23 020	348.9	80.0
4 000	40 500	2.7526	33 400	23 870	351.8	88.0

TABLE No. 5.—ECCENTRIC BREAKING LOADS FOR VARIOUS ECCENTRICITIES (n = A FRACTION OF THE DIAMETER) OF ROUND-ENDED SOLID 1-IN. SQUARE CAST-IRON PILLARS.

$$W_1 = \pm \sqrt{\left(\frac{W - T - 6\,n\,W}{2}\right)^2 + T\,W} + \frac{W - T - 6\,n\,W}{2}$$

Central breaking loads, W.	Length, L.	Breaking loads for--				
		$n = 0.1.$	$n = 0.3.$	$n = 0.5.$	$n = 0.7.$	$n = 1.0.$
84 000	5.0	46 500	13 840	7 040	4 640	3 060
72 000	6.0	45 130	13 260	7 000	4 590	3 040
62 000	7.0	41 500	12 670	6 760	4 530	3 010
56 000	8.0	36 680	12 260	6 650	4 480	3 000
50 000	9.1	30 350	11 800	6 530	4 430	2 980
45 000	10.1	27 850	11 360	6 400	4 380	2 950
41 000	11.1	25 930	10 970	6 290	4 330	2 930
37 000	12.3	23 800	10 540	6 150	4 270	2 900
35 000	13.0	22 680	10 310	6 080	4 250	2 880
32 000	14.3	21 150	10 000	6 000	4 200	2 880
30 000	15.3	20 000	9 670	5 860	4 130	2 840
27 000	17.0	18 350	9 220	5 700	4 050	2 800
24 000	19.4	16 600	8 770	5 470	3 960	2 760
21 000	21.5	14 920	8 190	5 300	3 940	2 710
17 000	25.3	12 500	7 360	4 950	3 660	2 620
13 000	30.1	10 000	6 350	4 470	3 410	2 500
10 000	35.0	8 000	5 430	4 000	3 120	2 340
5 000	50.0	4 350	3 000	2 700	2 160	1 860

TABLE No. 6.—ECCENTRIC BREAKING LOADS FOR VARIOUS ECCENTRICITIES (n = A FRACTION OF THE DIAMETER) OF ROUND-ENDED SOLID 1-IN. SQUARE WROUGHT-IRON PILLARS.

$$W_1 = \pm \sqrt{\left(\frac{C + W + 6\,n\,W}{2}\right)^2 - C\,W} + \frac{C + W + 6\,n\,W}{2}$$

Central breaking load, W.	Length, L.	Breaking loads for—				
		$n = 0.1.$	$n = 0.3.$	$n = 0.5.$	$n = 0.7.$	$n = 1.0.$
49 000	7.0	23 930	17 960	11 850	8 550	6 560
40 000	10.0	22 170	13 860	10 310	8 270	6 320
36 000	12.1	21 180	13 400	10 000	8 100	6 290
30 000	16.3	19 340	12 650	9 672	7 790	6 100
25 000	20.5	17 430	11 800	9 100	7 450	5 980
21 000	24.6	15 600	10 930	8 570	7 090	5 640
18 000	28.4	14 020	10 150	8 070	6 740	5 430
16 000	31.3	12 470	9 480	7 120	6 460	5 240
14 000	34.8	12 090	8 840	6 930	6 100	5 030
12 000	38.3	10 240	8 050	6 690	5 740	4 710
10 000	43.9	8 780	7 140	6 000	5 270	4 420

TABLE No. 7 A.—A ROUND-ENDED SOLID 1-IN. SQUARE CAST-IRON PILLAR. $W = 48\,000$ LBS., $R = 67.7$ INS., $\delta = \frac{1}{6}$. WHEN LOADED IN THE CENTER WITH VARIOUS WEIGHTS $W_1 < W$.

Bending weights, W_1.	$\frac{L^2}{L_1^2}$	X.	pX.	R_1	δ_1	Compression due to bending moment.	$\frac{X}{6}$
48 000	1.00000	48 000	29 400	67.7	0.16666	0.16666	8 000
44 000	.86745	41 637	25 500	88.2	0.12812	0.10000	5 637
40 000	.70679	33 926	20 780	124.9	0.09047	0.05384	3 620
39 070	.6742	32 360	19 820	135.4	0.08333	0.04065	3 256
36 000	.55961	26 860	16 352	185.2	0.06100	0.02700	2 200
32 000	.44134	21 800	12 975	278.4	0.04059	0.01300	1 300
28 000	.33555	16 106	9 855	442.8	0.02552	0.00600	714
24 000	.23979	11 510	7 050	690.0	0.01655	0.00460	397
20 000	.17986	8 613	5 296	977.7	0.01155	0.00177	231
16 000	.12949	6 215	3 807	1 418.5	0.00800	0.00090	128
12 000	.08914	4 280	2 620	2 157.6	0.00528	0.00046	63
8 000	.05913	2 790	1 710	3 458.0	0.00330	0.00015	26
4 000	.02787	1 338	820	7 300.0	0.00155	0.00004	6.2
1 000	.00681	327	200	31 232.0	0.00036	0.00000	0.36

At the breaking point the deflection is 0.16666; hence the bending moment is 48 000 × 0.1666 = 8 000. To bend the pillar to half the breaking deflection, the bending weight is 39 070 lbs., and the bending moment 3 256 lbs. An endwise compression of 24 000 lbs. (one-half the breaking weight) results in a deflection of 0.01655, about $\frac{1}{10}$ of the breaking deflection and the bending moment is 24 000 × 0.01655 = 397, or about the twentieth part of the bending moment at the breaking point.

When the load is 16 000 lbs. the deflection is reduced to 0.008, and the bending moment is 16 000 × 0.008 = 128 lbs., about the sixtieth part of the bending moment at the point of breaking. It may be observed here that the resistance to bending in this case being six times the bending moment, 6 × 128 = 768 lbs., hence the strain at the intrados is 16 768 lbs., consisting of the strain caused by resistance to the bending moment and that of vertical compression caused by the bending weight.

TABLE No. 7 B.—A SOLID ROUND-ENDED 1-IN. SQUARE WROUGHT-IRON PILLAR, 19.6 INS. LONG, LOADED IN THE CENTER WITH VARIOUS WEIGHTS $W_1 < W$.

W_1	$L.$	L^2	$\frac{L_2}{L_1^2}$	$pX.$	$X.$	δ_1
26 000	19.6	374.16	....	15 926	26 000	0.16666
24 000	21.4	457.96	0.81701	13 010	21 240	0.10300
22 000	23.5	552.25	0.67752	10 790	17 600	0.07224
20 000	25.8	665.64	0.56210	8 950	14 610	0.04758
18 000	28.4	806.56	0.46389	7 390	12 060	0 03568
16 000	31.3	979.69	0.38202	6 080	9 932	0.02900
14 000	34.8	1 211.04	0.30895	4 920	8 030	0.02292
12 000	38.8	1 505.44	0.24854	3 960	6 460	0.01828
10 000	43.9	1 927.21	0.19414	3 090	5 040	0.01305
8 000	50.0	2 500.00	0.14096	2 240	3 670	0.00900
6 000	59.6	3 552.16	0.10533	1 670	2 744	0.00406
4 000	74.4	5 535.36	0.06760	1 120	1 760	0.00112
2 000	100.7	10 140.00	0.03689	587	960	0.00091

TABLE No. 7a.—IF A SOLID 1-IN. SQUARE CAST-IRON PILLAR IS LOADED IN CENTER WITH WEIGHTS VARYING FROM 48 000 LBS. (ITS BREAKING WEIGHT) TO 24 000 LBS., AND IF BY ANY OF THESE LOADS IT WERE BENT TO ONE-HALF ITS BREAKING DEFLECTION ON THE ASSUMPTION THAT $\frac{S - W_1}{6\ W_1} = \delta_1$, THEN $S - W_1$ WILL GIVE A RADIUS GREATER THAN $R_1 = 135.4$. HENCE $X > S - W_1$, AND THERE IS A HORIZONTAL SHIFTING OF THE PARTICLES COMPOSING THE PILLAR.

W_1	$S.$	$S - W_1$	$p\ (S - W_1)$	$R.$
48 000	72 000	24 000	14 600	140.3
44 000	66 000	22 000	13 475	172.7
40 000	60 000	20 000	12 250	219.5
36 000	54 000	18 000	11 025	286.8
32 000	48 000	16 000	9 800	381.1
28 000	42 000	14 000	8 575	514.9
24 000	36 000	12 000	7 300	664 8

TABLE No. 8.—SAFE LOADS OF ROUND-ENDED SOLID 1-IN. SQUARE CAST-IRON PILLARS LOADED IN THE CENTER. MAXIMUM STRAIN = 16 000 LBS. GIVEN FOR ALL PILLAR LENGTHS, BOTH IN DIAMETERS AND RADII OF GYRATION.

Lengths in diameters.	Lengths in radii of gyration.	Safe load.	Breaking weights.
6.0	20.7	15 820	....
6.2	21.5	15 750	72 000
6.7	23.2	15 660	65 000
7.0	24.2	15 630	....
7.3	25.3	15 540	60 000
8.0	27.7	15 510	....
8.3	28.7	15 480	54 000
8.9	30.8	15 410	51 000
9.0	31.1	15 400	....
9.5	32.9	15 300	48 000
9.7	33.5	15 260	47 000
10.0	34.6	15 200	....
10.1	35.0	15 150	45 000
10.6	36.7	14 900	43 000
11.0	38.1	14 700	....
11.1	38.4	14 660	41 000
11.3	39.1	14 580	40 000
11.6	40.2	14 460	39 000
11.8	40.9	14 380	38 000
12.0	41.5	14 300	....
12.7	44.0	13 950	36 000
13.0	45.0	13 800	....
13.5	46.7	13 510	34 000
14.0	48.4	13 220	....
14.3	49.5	13 080	31 000
15.0	51.9	12 750	....
15.3	53.0	12 590	30 000
15.8	54.7	12 580	29 000
16.0	55.3	12 200	....
16.4	56.8	12 030	28 000
17.0	58.9	11 780	27 000
17.6	61.0	11 440	26 000
18.0	62.3	11 220	....
18.3	63.4	11 090	25 000
19.0	65.8	10 800	....
19.4	67.2	10 620	24 000
19.8	68.6	10 440	23 000
20.0	69.2	10 350	....
20.6	71.3	10 080	22 000
21.0	72.7	9 900	....
21.5	74.5	9 700	21 000
22.0	76 2	9 500	....
22.4	77.6	9 380	20 000
23.0	79.6	9 190	....
23.3	80.7	8 920	19 000
24.0	83.1	8 800	....
24.3	84.2	8 710	18 000
25.0	86.6	8 500	....
25.3	87.6	8 410	17 000
26.0	90.0	8 200	....
26.4	91.4	8 080	16 000
27.0	93.5	7 900	....
27.6	95.6	7 750	15 000

Lengths in diameters.	Lengths in radii of gyration.	Safe load.	Breaking load.
28.0	96.9	7 650	....
28.8	99.8	7 450	14 000
29.0	100.4	7 400	....
30.0	102.9	7 100	....
30.1	104.3	7 070	13 000
31.0	107.3	6 800	....
31.8	110.1	6 640	12 000
32.0	110.8	6 600	....
33.0	114.3	6 400	....
33.2	115.0	6 360	11 000
34.0	117.7	6 200	....
35.0	121.2	5 920	10 000
36.0	124.7	5 640	....
37.0	128.2	5 360	9 000
38.0	131.6	5 080	....
39.0	135.0	4 780	....
39.4	136.4	4 500	8 000
40.0	138.5	4 280	....
41.0	142.0	4 060	....
42.0	145.4	3 780	....
42.3	146.5	3 600	7 000
43.0	148.9	3 450	....
44.0	152.4	3 300	....
45.0	155.8	3 150	....
45.6	158.0	3 000	6 000
46.0	159.3	2 800	....
47.0	162.8	2 600	....
48.0	166.2	2 400	....
49.0	169 7	2 200	....
50.0	173.2	2 000	5 000

To find the safe load (L_{1s}.) for eccentric loads.

Let centric safe loads be L_s and eccentric safe loads L_{1s}.

Let centric breaking weights be W and eccentric breaking weights be W_1, then L_{1s}: $L_s = W_1 : W$ and $L_{1s} = \frac{L_s W_1}{W}$

TABLE No. 9.—SAFE LOADS OF ROUND-ENDED SOLID 1-IN. SQUARE WROUGHT-IRON PILLARS, LOADED IN THE CENTER. MAXIMUM STRAIN = 12 000 LBS. FOR ALL PILLAR LENGTHS GIVEN IN DIAMETERS AND IN RADII OF GYRATION. FORMULA FOR ECCENTRIC SAFE LOADS IN TABLE No. 8.

Length in diameters.	Lengths in radii of gyration.	Safe load.	Breaking weight.	Length in diameters.	Lengths in radii of gyration.	Safe loads.	Breaking weights.
10.0	34.6	11 810	......	41.3	143.1	4 970	11 000
10.5	36.4	11 800	39 000	42.0	145.4	4 850	......
11.0	38.1	11 800	......	43.0	148.8	4 650	......
11.6	40.2	11 800	37 000	43.9	152.0	4 470	10 000
12.0	41.5	11 790	......	44.0	152.4	4 450	......
13.0	45.0	11 750	......	45.0	155.8	4 280	......
13.5	46.8	11 700	34 000	46.0	159.3	4 110	......
14.0	48.4	11 700	......	47.0	162.8	3 950	9 000
15.0	51.9	11 600	......	48.0	166.2	3 880	......
15.6	54.0	11 550	31 000	49.0	169.7	3 650	......
16.0	55 4	11 520	......	50.0	173.2	3 500	......
16.3	56.5	11 500	30 000	51.0	176.6	3 380	......
17.0	58.8	11 400	......	52.0	180.1	3 240	......
17.1	59.2	11 390	29 000	53.0	183.5	3 100	......
18.0	62.3	11 200	28 000	54.0	187.0	3 000	......
18.7	64.8	11 110	27 000	54.5	188.8	2 950	7 000
19.0	65.8	10 900	......	55.0	190.3	2 900	......
19.6	67.7	10 720	26 000	56.0	193.8	2 770	......
20.0	69.2	10 600	......	57.0	197.4	2 650	......
20.5	71.0	10 400	25 000	58.0	200.9	2 550	......
21.0	72.7	10 200	......	59.0	204.3	2 470	......
21.4	74.1	10 060	......	59.6	206.3	2 430	6 000
22.0	76.2	9 850	......	60.0	207.8	2 400	......
22.5	78.0	9 700	23 000	61.0	211.3	2 300	......
23.0	79.6	9 550	......	62.0	214.7	2 200	......
23.5	81.7	9 250	22 000	63.0	218.2	2 120	......
24.0	84.1	9 150	......	64.0	221.7	2 070	......
24.6	85.2	8 990	21 000	65.0	224.9	2 020	......
25.0	87.6	8 880	......	65.7	227.6	1 990	5 000
26.0	90.0	8 600	20 000	66.0	228.6	1 980	......
27.0	93.5	8 350	......	67.0	232.1	1 900	......
27.1	93.7	8 320	19 000	68.0	235.6	1 850	......
28.0	96.9	8 070	......	69.0	239.0	1 800	......
28.4	98.4	7 960	18 000	70.0	242.5	1 770	......
29.0	100.4	7 800	......	71.0	245.9	1 730	......
29.7	102.7	7 600	17 000	72.0	249.4	1 700	......
30.0	103.9	7 520	......	73.0	252.9	1 650	......
31.0	107.3	7 300	......	74.0	256.3	1 600	......
31.3	108.4	7 200	16 000	75.0	259.8	1 550	......
32.0	110.8	7 000	......	76.0	263.3	1 500	......
33.0	114.3	6 780	15 000	77.0	266.7	1 450	......
34.0	117.7	6 550	......	78.0	270.2	1 400	......
34.8	120.5	6 340	14 000	79.0	273.7	1 350	......
35.0	121.2	6 290	......	80.0	277.1	1 300	......
36.0	124.7	6 090	......	81.0	280.5	1 250	......
36.7	127.1	5 900	13 000	82.0	284.0	1 200	......
37.0	128.1	5 820	......	83.0	284.0	1 250	......
38.0	131.6	5 650	......	84.0	290.9	1 100	......
38.8	134.4	5 470	12 000	85.0	294.4	1 050	......
39.0	135.0	5 420	......	86.0	297.9	1 000	......
40.0	138.5	5 210	......	87.0	301.3	950	......
41.0	142.0	5 020	......	88.0	304.8	900	......
......	......	......	......	89.0	308.2	850	......
......	......	......	......	90.0	311.7	800	......

TABLE No. 10.—COMPRESSION OF COMMON HARD BRICKWORK IN ACCORDANCE WITH EXPERIMENTS AT THE WATERTOWN ARSENAL. MODULUS OF ELASTICITY = 160,000 NEARLY.

Weights. Pounds per square inch.	Compression. In parts of unity.	Weights. Pounds per square inch.	Compression. In parts of unity.
50	....	1 100	0.00680
100	0.00122	1 150	0.00722
150	0.00164	1 200	0.00764
200	0.00200	1 250	0.00783
250	0.00233	1 300	0.00813
300	0.00267	1 350	0.00855
350	0.00300	1 400	0.00892
400	0.00327	1 450	0.00900
450	0.00352	1 500	0.00928
500	0.00379	1 550	0.00946
550	0.00410	1 600	0.00960
600	0.00437	1 650	0.01000
650	0.00457	1 700	0.01013
700	0.00479	1 750	0.01031
750	0.00505	1 800	0.01056
800	0.00531	1 850	0.01108
850	0.00566	1 900	0.01116
900	0.00590	1 950	0.01147
950	0.00619	2 000	0.01171
1 000	0.00631	2 050	0.01204
1 050	0.00660	2 100	0.01238

TABLE No. 11.—PIERS OR WALLS OF COMMON HARD BRICK LAID IN BEST ROSENDALE CEMENT WITH 2 PARTS OF SAND, OR IN PORTLAND CEMENT WITH 3 PARTS OF SAND.—MAXIMUM STRAIN FOR SAFE LOADS, 300 LBS.

Breaking weight.	Length.	L^2	δ	Safe load.	δ_1
2 000	0.0	0.00	0.00000	300	0.00000
1 900	9.5	90.25	0.00868	297	0.00056
1 800	9.8	96.04	0.01847	295	0.00278
1 700	10.1	102.01	0.03000	290	0.00500
1 600	10.4	108.16	0.04160	285	0.00700
1 500	10.8	116.64	0.05600	280	0.01040
1 400	11.1	123.21	0.07124	275	0.01405
1 300	11.6	134.56	0.09000	270	0.01870
1 200	12.0	144.00	0 11080	260	0.02510
1 100	12.3	151.29	0.16000	250	0.03150
1 000	13.2	174.24	0.16666	240	0.04119
900	14.0	196.00	0.16666	225	0.04119
800	15.0	225.00	0.16666	200	0.04119
700	16.0	256.00	0.16666	175	0.04119
600	17.0	289.00	0.16666	150	0.04119
500	18.7	349.69	0.16666	125	0.04119
400	21.0	441.00	0.16666	100	0.04119
300	24.4	595.36	0.16666	75	0.04119
200	29.6	876.16	0.16666	50	0.04119
100	42.0	1 764.00	0.16666	25	0.04119

For sandstone safe loads may be increased by 0 — 40 per cent.
" granite " " " 60 — 160 "
" marble " " " 40 — 100 "
" limestone " " " 10 — 25 "

TABLE No. 12.—YELLOW PINE, SQUARE WOODEN POSTS, STRAIGHT GRAINED, PERFECTLY DRY AND LOADED IN THE CENTER.—WHEN NOT DRY, ONE-HALF THE SAFE LOAD TO BE TAKEN.—MAXIMUM STRAIN FOR SAFE LOADS, 800 LBS.

Length in diameters.	Breaking weight.	Deflection.	Safe load.	Deflection.	Safe load.	Safe load.
0	8 000	......	800	.....	....	....
15	7 800	.00428	795	.0010	....	....
16	6 875	.02727	790	.0040	....	....
17	6 075	.05281	770	.0075	....	....
18	5 425	.07910	755	.0125	....	....
19	4 900	.10544	720	.0175	....	....
20	4 400	.13636	695	.0225	....	....
21	3 975	.16834	675	.0300	....	....
22	3 650	.20000	650	.0375	....	....
23	3 525	.21158	625	.0450	....	....
24	3 050	.27050	605	.0550	540	....
25	2 825	.30531	580	.0650	460	....
26	2 625	.34127	555	.0750	400	....
27	2 400	.39000	530	.0850	320	....
28	2 250	.42600	505	.0975	250	....
29	2 075	.47590	475	.1100	220	460
30	1 950	.51710	460	.1225	190	375
35	1 400	.78571	350	.1975	90	150
40	1 100	1.0454	290	.2900	50	90
45	875	1.2810	240	.3900	30	60
50	700	1.7380	200	.4975	20	40
55	575	2.1521	165	.6150	10	30
60	500	2.5	135	.7300	5	20

1896. FEBRUARY. No. 2.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

PAPERS.

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THE TWENTY-EIGHTH STREET CENTRAL STATION OF THE UNITED ELECTRIC LIGHT AND POWER COMPANY.

By H. W. YORK, Jun. Am. Soc. C. E.

TO BE PRESENTED MARCH 18TH, 1896.

The history of the development of the electrical industries for the past few years probably presents the most remarkable example of rapid growth ever recorded, and nowhere is this better exemplified than in the central stations of this and other cities, where the current is generated for distribution over areas of greater or less extent for the supply of light and power. In isolated plants the apparatus is generally small and simple in construction, and the generation of electricity is a matter of secondary importance; the cost of the current generated is comparatively immaterial, and a plant once installed runs until it refuses absolutely to do any more work, when it is sold for junk and another put in its place. In central stations, however, this is not the case. Here the cost of the current generated is a matter of the first importance, and as the growth of business calls constantly for additional capacity, and competition demands constantly better service

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

and cheaper methods of generation and distribution, in such stations will be found the results of the latest discoveries, inventions and improvements, affecting the entire apparatus required for the generation of current, from the boilers to the switchboard. Here everything is being constantly revolutionized; what was good practice yesterday is obsolete to-day, and what a few years ago was looked upon with wonder and admiration is laughed at to-day as being old-fashioned and out of date.

Boiler-making has been almost entirely revolutionized to meet the requirements of the electrical business; engine-building has undergone changes even more remarkable, but it is in the strictly electrical apparatus that the greatest strides have been made, the other industries simply following in the wake as rapidly as possible and trying to meet the ever-changing conditions. In dynamo-building one of the most noticeable changes to the layman is the increased size of the units. A few years ago a 600-light incandescent dynamo was considered a monstrosity, and when the first were built wiseacres predicted that they could never be made to operate successfully, that they were too big and awkward to handle, and that it was carrying too many eggs in one basket to have 600 lights on one dynamo. To-day a 6 000-light dynamo is considered little more than a baby, while a 600-light machine is scarcely large enough to excite the field of a good-size alternator.

With the increase in the size of the dynamo there has naturally come a reduction in the speed of the armature, making it possible to connect the armature shaft directly to the engine shaft, either by a rigid or a flexible coupling, and to do away with belts, which, under the conditions and at the speeds—seldom less than 6 000 ft. per minute—required in most electrical work are a source of never-ending trouble; this is certainly a long step in the right direction. The author does not wish to incur the enmity of belt men by running down their goods. Belts are very good things and all right in their place, but an electric station is no place for them.

With these changes has come naturally an increased efficiency and various other improvements which, though fully as important as those mentioned, are less noticeable to a person unfamiliar with electrical matters.

The author has been connected for a number of years with the United Electric Light and Power Company, a corporation supplying

electricity for all purposes in the city of New York and formed by the combination of interests of the oldest companies in the field. The stations which the new company acquired and attempted to operate had all been doing service for several years, and the apparatus was naturally somewhat antiquated.

After making numerous changes and improvements, both in the methods of generation and distribution of current, there came a time when alterations would no longer answer the purpose, and the author was instructed to design and erect a new station, to take the place of all the old ones and embody, as far as possible, the best modern practice for the economical generation and distribution of current, as well as the most efficient and reliable service.

The first portion of this station has been erected, and the apparatus has been installed and is in operation, and it is intended to give in this paper a brief description of it as an instance of modern practice in this particular line.

When the subject of a new station was taken up, one of the stations operated by the company was on the south side of East Twenty-ninth Street, the property extending west 280 ft. from the East River and including also eight lots directly in the rear of the station on the north side of East Twenty-eighth Street, but having no water front. This Twenty-eighth Street property was vacant, with the exception of a few small one-story buildings, and was used as a storage yard. This was considered a good central location for the district to be covered, from the Battery to Fifty-ninth Street, and it was decided to design the station to run from street to street, and to erect and equip first the Twenty-eighth Street half, which would have sufficient capacity to take care of the load of all of the present stations, and then to tear down the old station and continue the new one through to Twenty-ninth Street, to provide for future growth of the business. The Twenty-eighth Street half is now erected, and sufficient apparatus has been installed to care for all the load, with the exception of that carried by the old Twenty-ninth Street plant. It is the intention to install during the coming summer the remainder of the machinery in the half already erected, and then remove the Twenty-ninth Street station and complete the new one.

One of the first considerations in laying out work in a large city where property is so valuable as in New York is economy of space, and

in this connection the author considers it worthy of note that in this station 20 000 H. P. of engines, together with the boilers, pumps, heaters, condensing apparatus, dynamos and switchboard, and storage for 6 000 tons of coal, are all on a plot of ground 160 ft. 11 ins. by 197 ft. 6 ins. All machinery, including the boilers, is on the ground floor, and yet there is plenty of light, air and ample space for working around all the apparatus, both for its ordinary operation and for making repairs.

The building already erected has a frontage of 160 ft. 11 ins., and is a steel frame structure with a brick filling in the walls, except on the north end, which is covered by a corrugated iron curtain wall which will be removed when the Twenty-ninth Street side is built. Figs. 1, 2 and 3 give a general idea of the construction of the building. Fig. 1 is a cross-section of the entire structure, Fig. 2 a longitudinal section through boiler room, and Fig. 3 the roof plan; Fig. 4 shows the front elevation of the building as it appears from Twenty-eighth Street. This entire front wall is hollow and is carried up above the roof, to prevent the noise from the machinery annoying the patients in Bellevue Hospital, which is directly across the street. The wall is really composed of two walls, one 12 ins. thick on the outside, and one 8 ins. thick on the inside, with a 2-in. air space between them. These two walls are bonded together at every sixth course vertically by bricks spaced 20 ins. horizontally, as shown in detail in Fig. 5.

Double windows are also placed on this side of the building, to prevent the noise of the machinery from causing annoyance, and this arrangement has been so successful that, standing directly in front of the building, it is impossible to tell whether or not the machinery is in operation. The foundations for all the machinery rest on solid rock, as do the foundations for the building itself, with the exception of one small corner which has no great weight to carry.

To prevent the transmission of any possible vibration to the adjoining buildings, the foundation walls were kept 1 in. away, and the space filled with sand up to the surface of the ground. Above this point the adjoining walls were covered with tarred paper and the brickwork built against this, thus preventing any possible bond between the brickwork of the station and that of the adjoining buildings. As a matter of fact these precautions were unnecessary as the station walls themselves are absolutely free from any perceptible vibration.

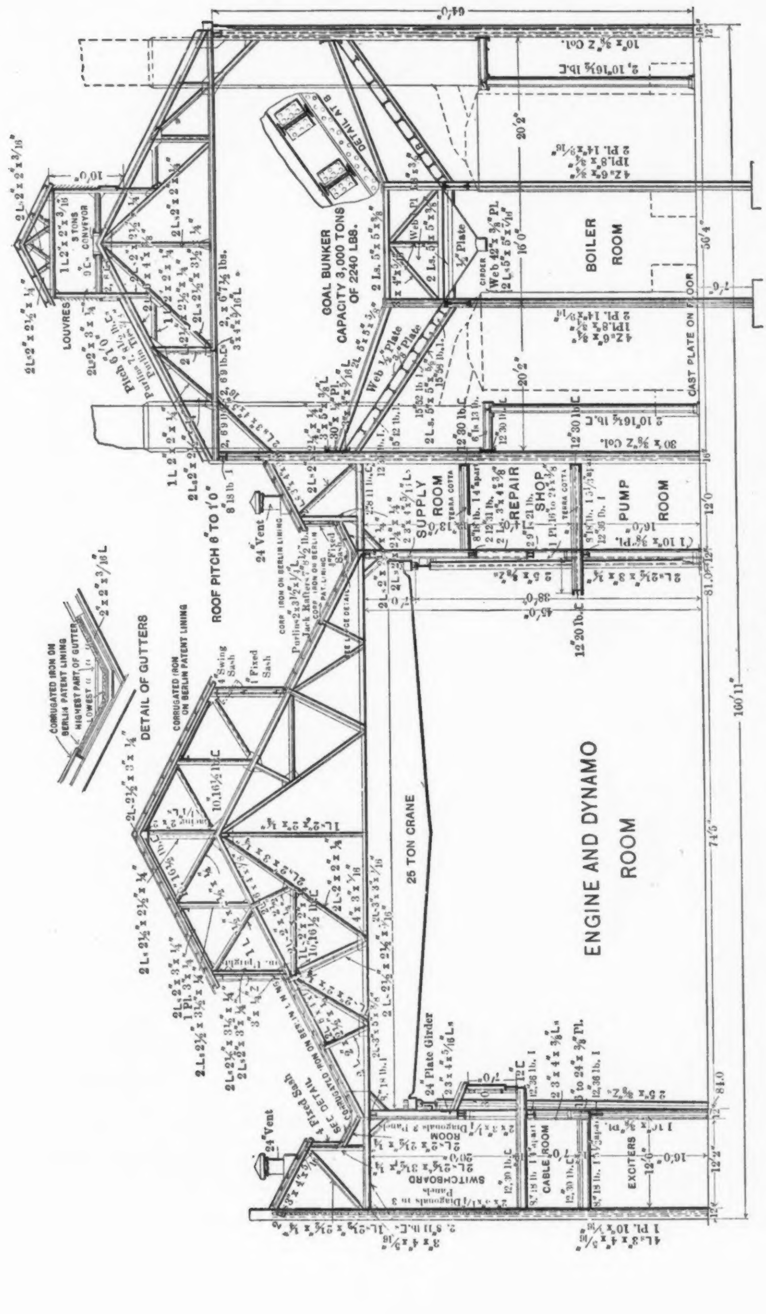
ENGINE AND DYNAMO
ROOM
25 TON CRANE
BOILER
ROOM
COAL BUNKER
CAPACITY 3,000 TONS
OF 2240 LBS.
SUPPLY
ROOM
REPAIR
SHOP
PUMP
ROOM
SWITCHBOARD
CABLE ROOM
EXCITERS
DETAIL OF GUTTERS
ROOF PITCH 6" TO 1'0"
LOUVRES
CAST PLATE ON FLOOR
24" Vent
24" Plate Girder
64'0"
160'11"
74'5"

FIG. 1.

It was the original intention to excavate down to the rock, which was only a few feet below the surface over the greater part of the area, remove the loose top rock and shale, and build up the foundations as shallow as possible. In the case of the engines it was the intention to build only enough foundation to carry the engines, and to hold them down by foundation bolts, which were to be secured by rusting oles drilled in the rock. The rock found, however, was practically useless for the purpose, being full of mica and quite soft, as is most of the rock on Manhattan Island. It became necessary, therefore, to take out enough of this material to allow masonry foundations to be built of sufficient weight to hold the machinery without anchorage. The foundations for the four main engines on each side were built together as one foundation, and are shown in Fig. 6. They are of hard brick, laid in mortar, composed of three parts sand and one of imported Portland cement. Fig. 7 shows a single engine foundation in detail. Fig. 8 is a plan of the foundation walls and piers of the building, which were constructed in the same manner as the engine foundations.

The masonry was all done by day's work, while the steel frame was let out by contract, as were the piping and all other work of any magnitude.

The boilers are of the upright water-tube type and are in 600 H. P. units. Aside from being economical in the generation of steam, they were selected especially because they occupy so little ground room per unit of capacity. Six are now installed, and six more are required to complete the half of the station now erected. Plate VI shows the arrangement of the boilers, as well as their appearance during erection. It will be seen that part of the boilers have all tubes in place, while the shell of one has just been set up, no tubes having been put in it.

The engine adopted is a Westinghouse double-acting, known as the "Columbian steepled compound," and is of the same type as those used in the lighting station at the World's Fair at Chicago. In fact, three of the engines at present installed were in service in that station. Fig. 9 shows one of these engines in section. The low-pressure cylinder is placed over the high pressure, and both pistons are connected to the same rod. The crank is enclosed in the same manner as is customary in the more familiar types of Westinghouse engines. The low-pressure valve is operated by a fixed eccentric placed inside

PLATE VI.
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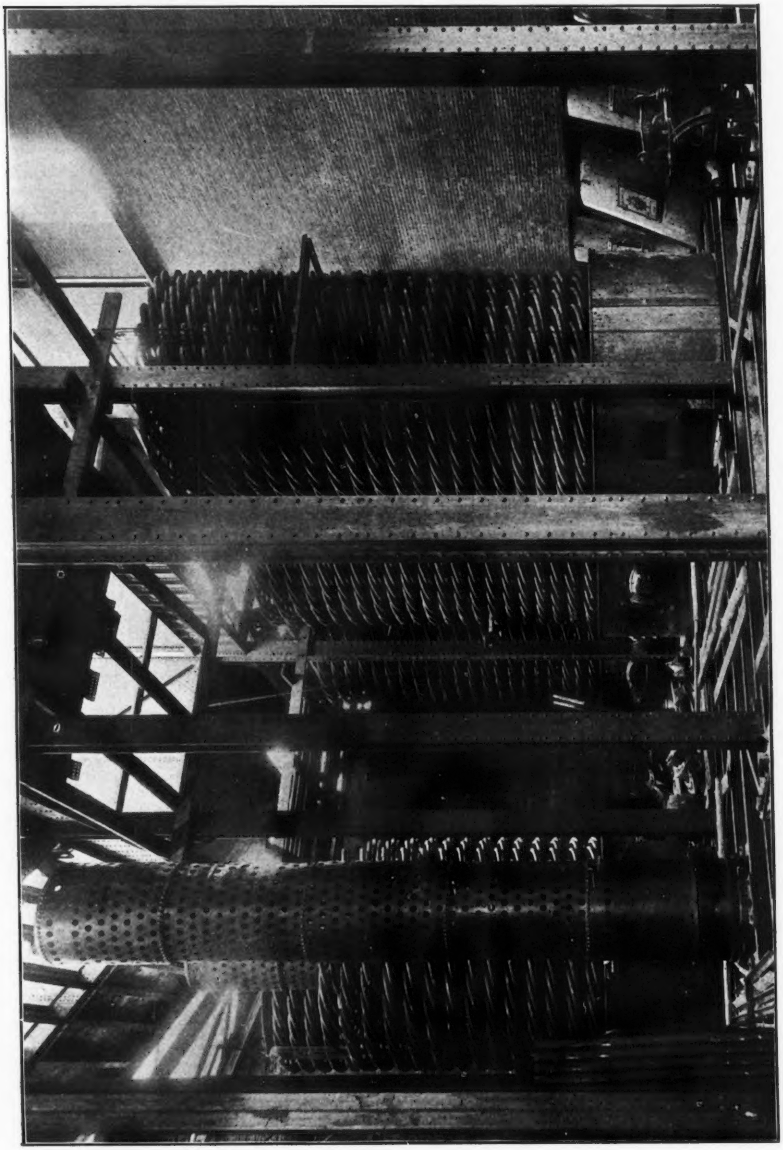

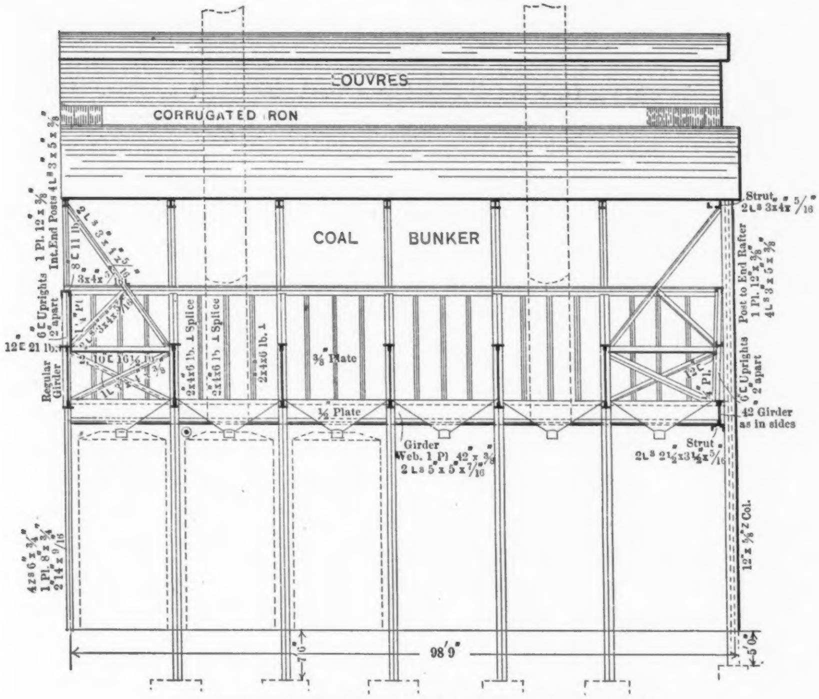

LONGITUDINAL SECTION THROUGH BOILER ROOM
FIG. 2.

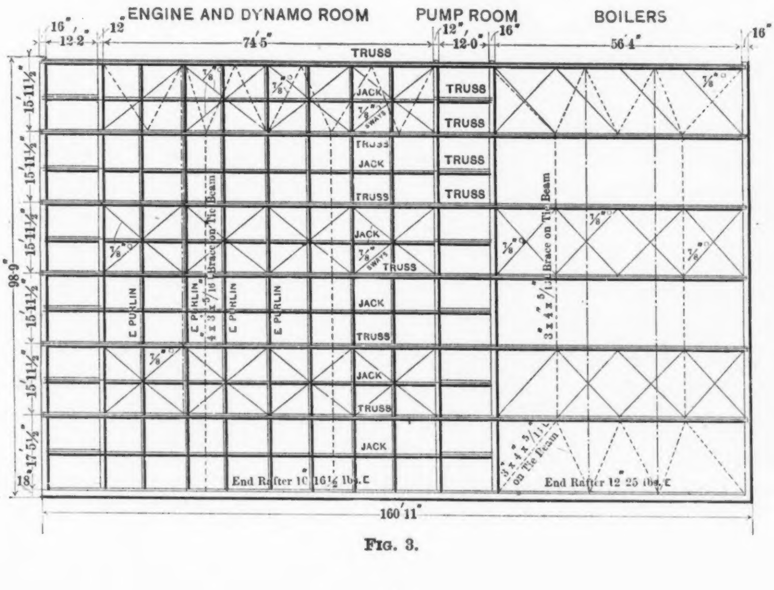

FIG. 3.

the crank case, while the high-pressure valve receives its motion from a shifting eccentric outside the crank case, operated automatically by the governor, which is placed on the shaft outside of the eccentric. The low-pressure valve is of the slide-valve type, while that for the high-pressure cylinder is a hollow piston valve, being constructed in this manner to allow the exhaust from the lower end of the high-pressure cylinder to pass up through it. On account of this construction it is impossible to cushion the valve itself, and this cushioning is accomplished by a plunger, receiving the same motion as the valve, which works in what is termed an inertia cylinder placed outside the crank case, as shown in the cut. This inertia balance is also used for working the engine by hand, the eccentric being first disconnected by throwing over a small hand wheel, and steam being admitted above or below the plunger by means of a small slide valve. The dimensions of these engines are as follows: Diameter high-pressure cylinder, 21½ ins.; diameter low-pressure cylinder, 37 ins.; stroke, 22 ins. The speed is 200 revolutions per minute and the rated horse-power 1 200 when operating condensing, with 150 lbs. initial steam pressure. Plate VII shows the four engines and dynamos already installed on the east side of the engine-room.

Each main engine is directly connected to a 600-kilowatt Westinghouse alternator by a rigid coupling, both engine and generator being set on a firm cast-iron bedplate, as shown in Fig. 12. The generator has but one bearing, the armature being swung between the engine and this single support. Four of these outfits are now erected in place, and four more will be required in the first half of the station. These generators are similar to those used in the lighting station at the World's Fair at Chicago, except that the armatures are wound for a different voltage and are slotted instead of toothed.

By this means the noise, which would be objectionable in a thickly populated district, is almost entirely done away with. The alternators are all arranged to give either single or two-phase current. This is accomplished in two of the four machines already in place by two separate armatures on the same shaft, set at the proper angle in relation to each other to give the form of current required. In the remaining two alternators the same result is accomplished with but a single armature.

For exciting the fields of the alternators 75-kilowatt direct-current

PLATE VII.
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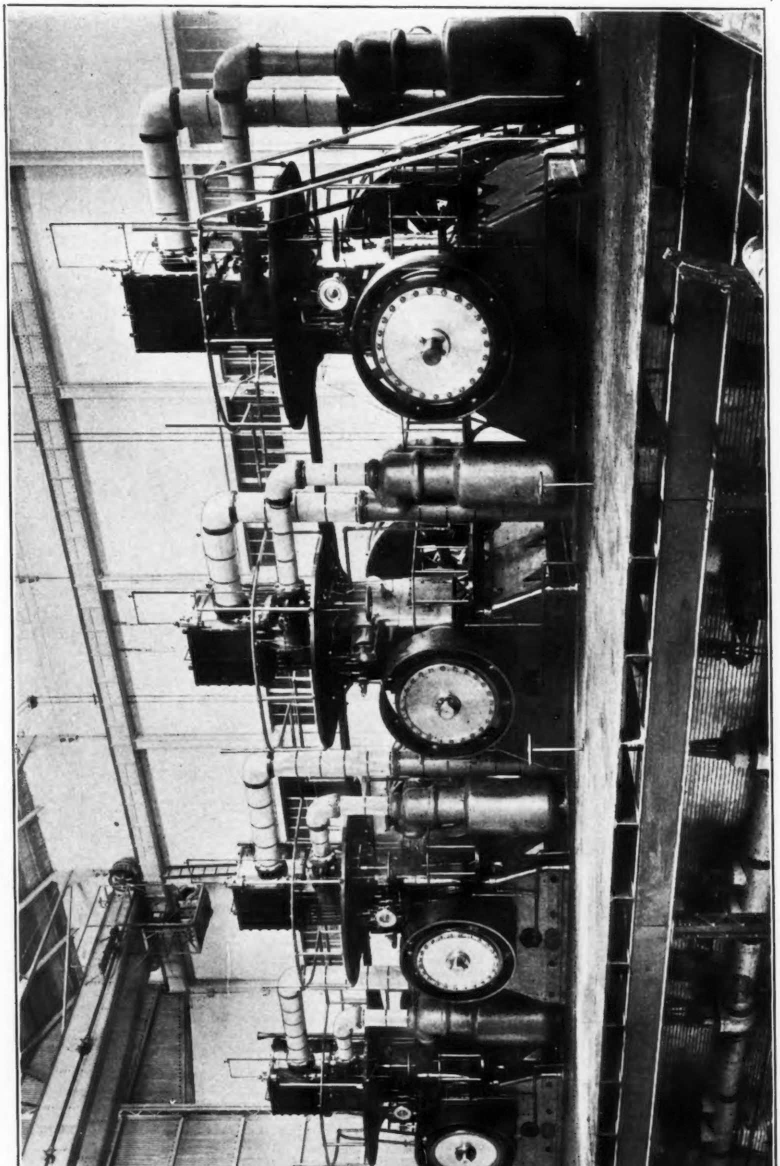

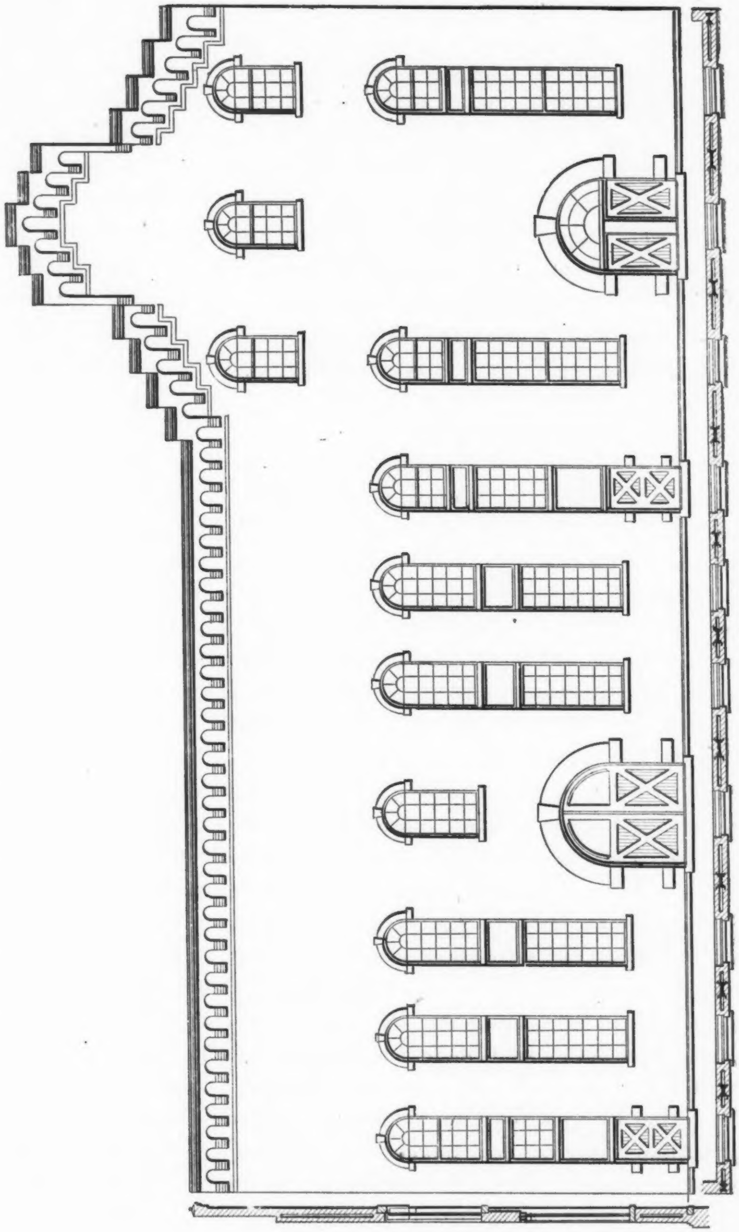

Fig. 4.

Westinghouse dynamos of the railway generator type are used. These are directly connected to 100 H.-P. Westinghouse single-acting tandem compound engines by means of a flexible coupling. Both the engine and the generator are too well known to require any description. Three of these outfits are provided for the eight alternators in the Twenty-eighth Street side of the station, and as each has sufficient capacity to excite four alternators, there is always one spare.

The feed pumps are arranged in the same manner as the exciters; that is, three are provided, any two of which are able to supply all the boilers in the Twenty-eighth Street side of the station at the time of the heaviest load, leaving one spare. These are compound duplex pumps 9 and 14 x 8 x 10 ins. The steam supply is controlled by a regulating valve operated by the pressure in the feed mains, so that this pressure is always kept constant.

The entire engine and dynamo-room is spanned by a three-motor electric crane of 25 tons capacity, which is shown in outline in Fig. 1. The span from center to center of the rails is 72 ft. 3¾ ins., and the crane itself weighs approximately 45 tons. While a crane of this size and character in a power station may appear to some to be in the nature of an extravagance, the author considers it quite the reverse, and his opinion is borne out in this instance, at least, by the facts, as it has saved in time and labor more than its cost in setting up the machinery now installed. Moreover, the first cost of the crane is very largely offset by the fact that its presence enabled the roof of the building to be made very light, just heavy enough, in fact, to provide for the wind and snow load, while it would have otherwise been necessary to make every roof truss strong enough to suspend the heaviest part of the engines or dynamos from it, thus materially increasing the cost.

The apparatus for handling coal and ashes is shown in Fig. 10. The conveyor consists of an endless chain of gravity buckets, which are loaded by means of a filler and can be dumped at any desired point. The driver is in the north end of the ventilator over the coal bunker. The coal filler is in a vault under the sidewalk and the coal is dumped into this apparatus through a grating situated at about the street level. After being deposited in the buckets, the coal is carried up into the ventilator over the coal bunker and dumped into any portion of the bunker desired. From the hoppers in the bottom of the bunker, the coal is spouted to the different boilers. The arrangement is such

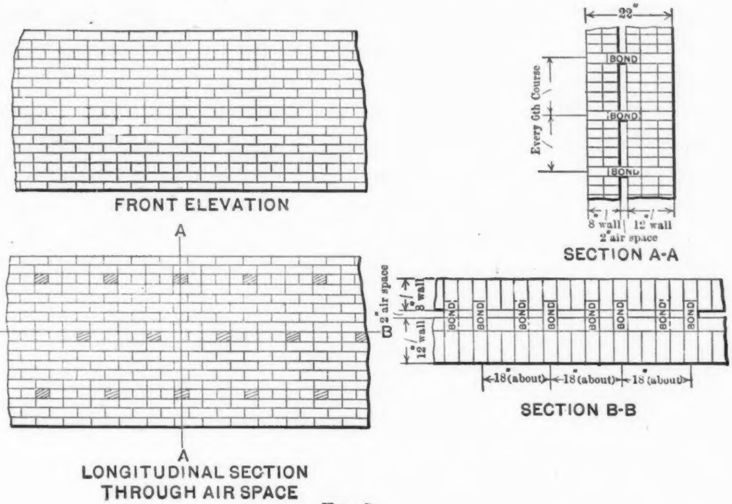
22"
BOND
Every 6th Course
8" wall
12" wall
2" air space
SECTION A-A
FRONT ELEVATION
A
B
LONGITUDINAL SECTION
THROUGH AIR SPACE
18"(about)
SECTION B-B

FIG. 5.

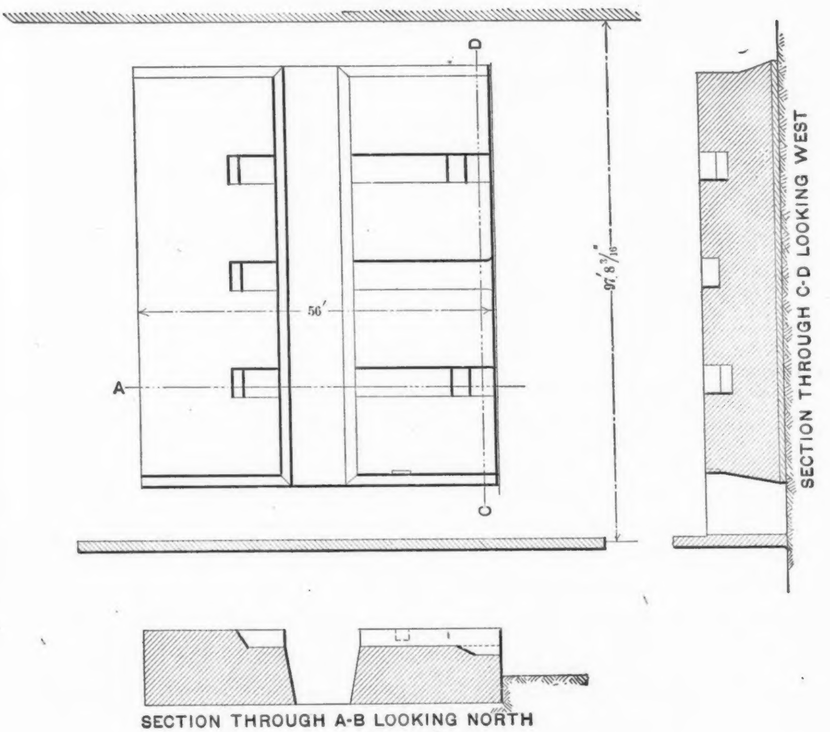
D
A
C
56'
97' 8 3/16"
SECTION THROUGH C-D LOOKING WEST
SECTION THROUGH A-B LOOKING NORTH

FIG 6.

that the coal trims itself and will continue running down the spouts, as required and without assistance, so long as any remains in the bunker.

When the Twenty-ninth Street side of the station is built, a second conveyor running at right angles to the present one will be put in to bring the coal from the water front. As the company does not own the bulkhead on the Twenty-eighth Street side, however, it is necessary to cart the coal at the present time.

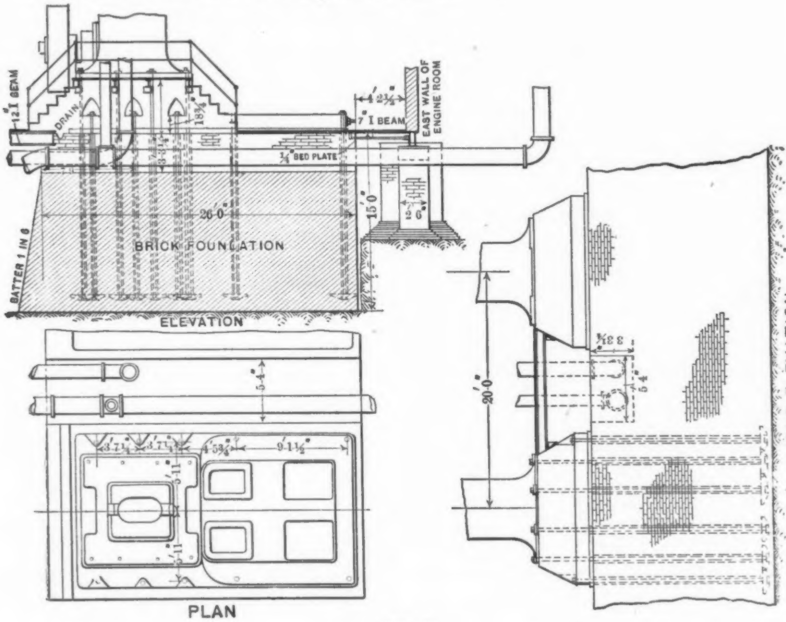

FIG. 7.

Under each boiler is an ash hopper delivering the ashes to a second movable filler, which deposits them in the buckets of the conveyor, when it is not used for coal. The conveyor dumps the ashes at a point from which they are spouted over to a tank in the southeast corner of the coal bunker. From this tank they are spouted down and out through the front of the building into carts. By this arrangement the same conveyor handles both the coal and the ashes, and neither is touched by a shovel, except that for the present the coal is fired by hand. This is a temporary arrangement, however, as the boilers are laid out and set with a view to the use of mechanical stokers, which will probably be applied in the near future.

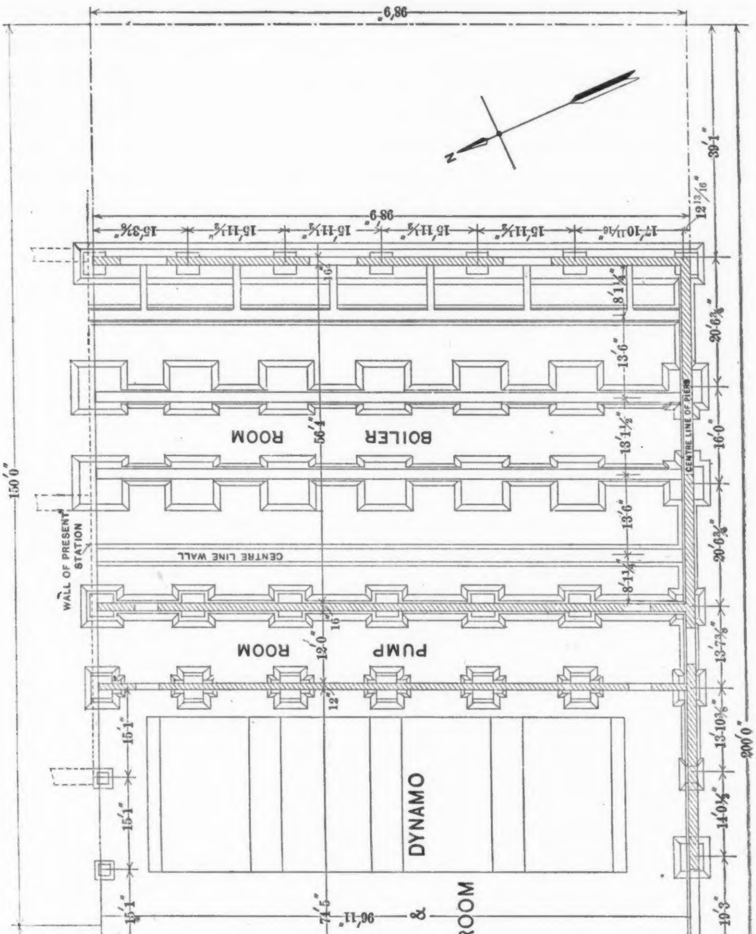
BOILER ROOM
PUMP ROOM
DYNAMO & ENGINE ROOM
EXCITER ROOM
WALL OF PRESENT STATION
CENTRE LINE WALL
CENTRE LINE OF PIERS

Fig. 8.

One feature of this station which is considered of special interest is the arrangement of the piping, which is laid out on what, for want of a better name, the author has termed the loop system. By this arrangement the size of the pipes required is reduced to a minimum, and without going to the expense of providing a duplicate set of pipes, steam can be shut off of any portion of the system without interfering with more than one engine or its equivalent boiler capacity. As this

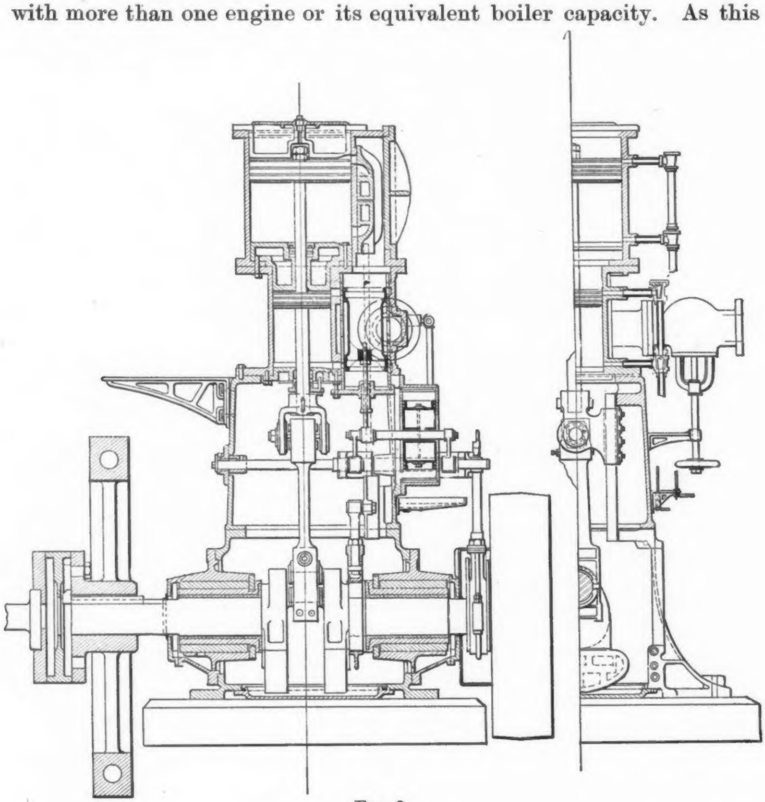

FIG. 9.

amount of spare is always carried, it follows that any portion of the steam-piping system can be cut out without interfering with the operation of the station, and the object of a duplicate set of pipes is thus accomplished without the expense of duplicate pipes and without occupying the space required for them.

The main steam and exhaust piping is shown in plan on Fig. 11 and in elevation on Fig. 12. A 16-in. header is run the length of the boiler-room

and a similar header is run the length of the engine-room between the two rows of foundations, and parallel to the boiler-room header. These are the largest live-steam pipes used and there will be none larger, even when the Twenty-ninth Street side of the station is complete and the entire 20 000 H. P. is installed. Each of these headers is divided into five sections by means of four gate-valves, located as shown, and each section of the boiler-room header is connected to the

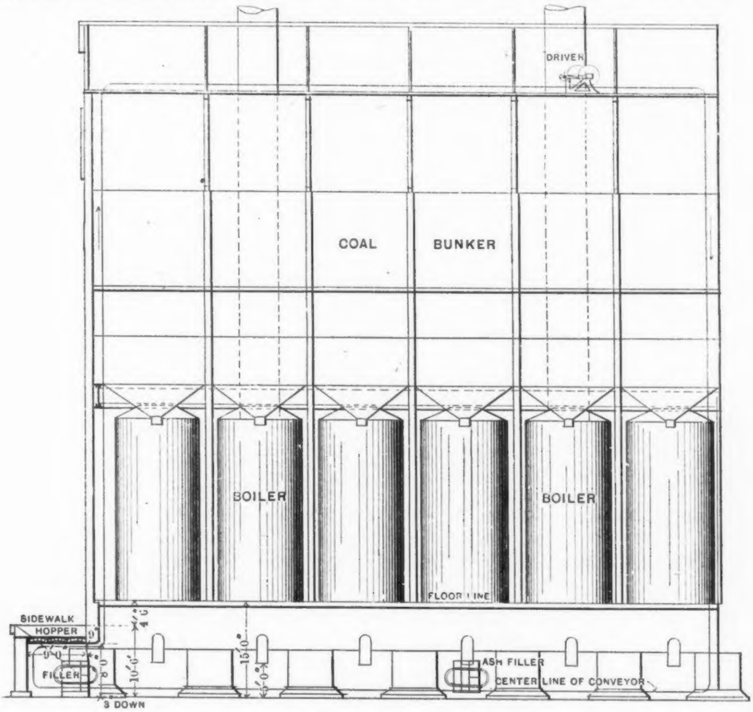

FIG. 10.

corresponding section of the engine-room header by a 14-in. branch rising from the top of one and discharging into the top of the other, a valve being placed on each end where a connection is made to the header. Each boiler has an independent connection to the boiler-room header, supplied with two stop valves, one in the customary position just beyond the safety valves, and the other at the point where the pipe enters the header. This second valve has its stem extended through the wall into the repair shop, so that in case of trouble any

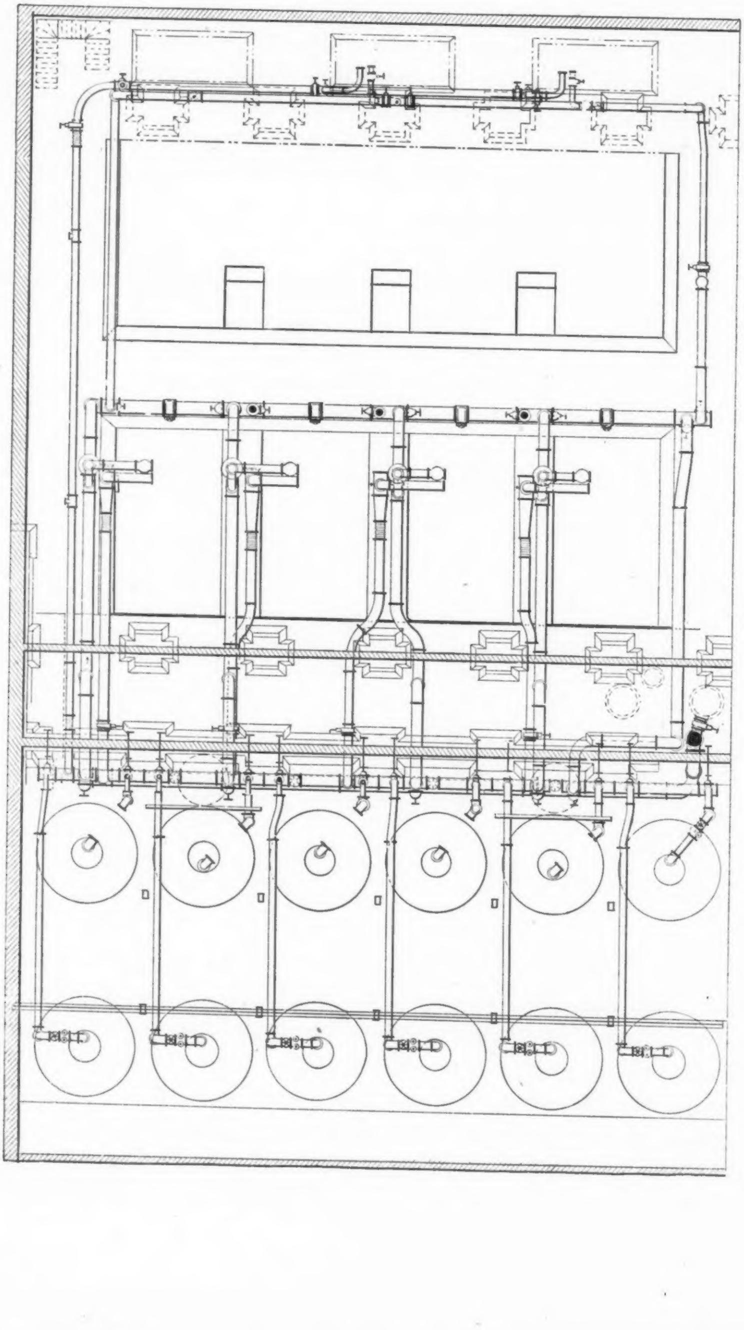

FIG. 11.

boiler may be cut out from a room having no communication with the boiler house.

Each engine on the east side of the engine-room is connected to one of the 14-in. branches previously mentioned, while outlets are left on the engine-room header for connections to the west row of engines as soon as they are placed in position. In case any section of the engine-room header is cut out, one engine connected to this section can be fed

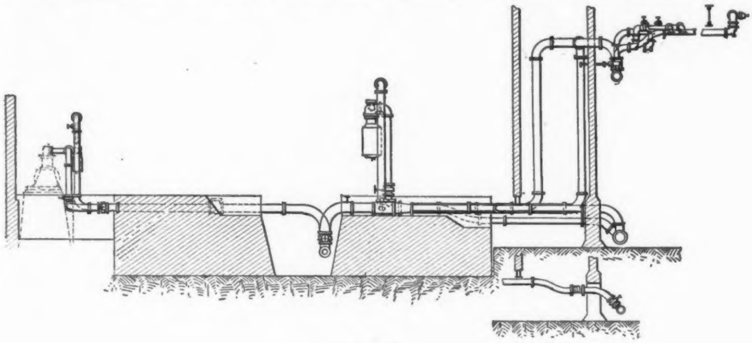

FIG. 12.

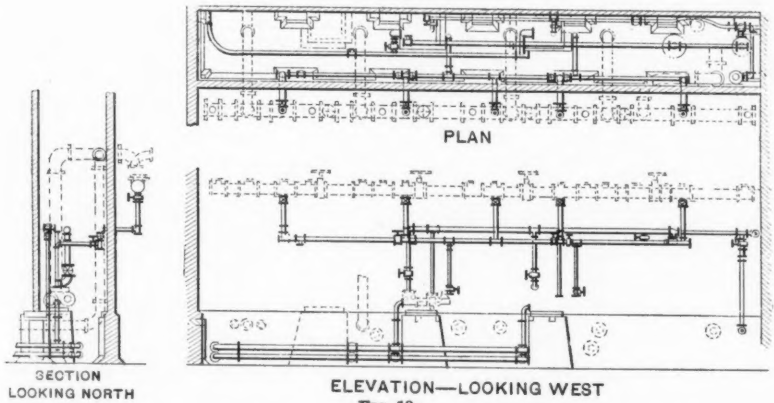

FIG. 13.

directly from the 14-in. branch, leaving only one which cannot be run, and in case any section of the boiler-room header is cut out, no engine need be shut down, as the one connected to the 14-in. branch can be fed back from the engine-room header. One 14-in. branch may at any time be cut out without interfering with the supply of steam, four of these branches being sufficient to furnish ample steam for all requirements.

The steam pipe for the exciter-engines runs from the north section of the engine-room header around through the exciter-room, and back to the south section of the same header, as shown in Fig. 11. This

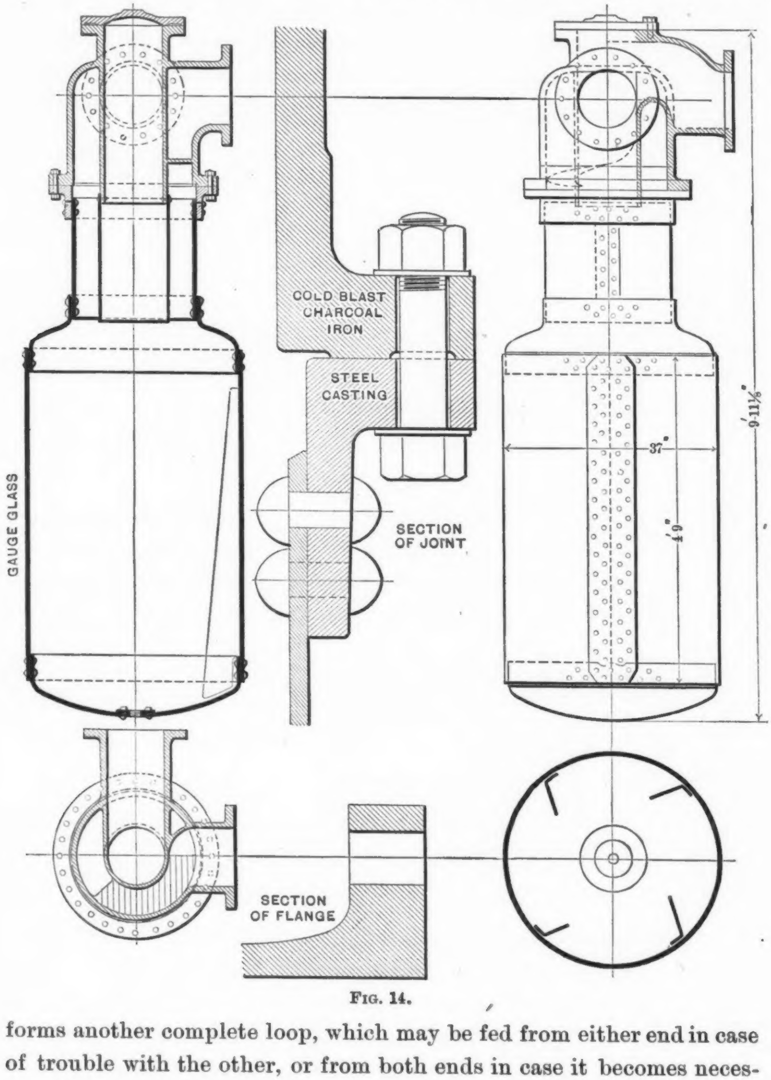

FIG. 14.

forms another complete loop, which may be fed from either end in case of trouble with the other, or from both ends in case it becomes necessary to cut out its center.

The steam pipe for the pump-room is arranged in practically the

same manner, as shown on Fig. 13, except that in this case the loop is fed not only at the two ends but also at three intermediate points, the same as the engine-room loop.

Another special feature of the steam piping of this station is the use of a combined separator and receiver, shown in detail in Fig. 14, as close to each engine as it is possible to place it. This receiver contains six times the volume of the high-pressure cylinder of the engine, and as the latest cut-off is one-third stroke, it follows that at full load there is at the engine eighteen times the volume of steam required for one stroke. This reservoir prevents the excessive drop in pressure in the pipe when the valve of the engine opens and a corresponding rise above boiler pressure when the valve closes, and keeps a practically uniform flow of steam in the pipe in one direction, allowing the use of smaller pipes than would otherwise be required, and doing away almost entirely with the vibration in the pipes caused by the intermittent flow of steam.

Two low points are provided in the steam piping, from which to take any condensation that may be deposited. One of these is the pump-room header, and the other a drip main under the engine-room header and connected to each of its sections.

Steam loops from both these points take all condensation and return the water to the boilers. A steam loop is also employed to return the water to the boilers from each of the separators.

Expansion of all live-steam pipes is provided for by long bends and swinging elbows, no expansion joints being used. The boiler-room header is supported by long hangers from the under side of the coal bunker, and is anchored in the middle of its length. The engine-room header is supported in cradles resting on rollers carried on piers, and is free to move horizontally in any direction. The vertical portion of each 14-in. branch connection is provided with a bracket ell at the bottom, which is supported from a pier by means of four $1\frac{1}{2}$-in. set screws, so adjusted as to take the weight of the pipe when hot. Hangers are also provided at the upper end of each of these vertical branches, but these carry no strain as long as the pipe is hot. When steam is shut off and the pipe contracts, the weight is transferred to the hangers, the bottom of the pipe lifting itself clear of the pier. This arrangement is for the purpose of confining the movement to the lower end of the pipe, where provision is made to take care of it.

All pipes, valves and fittings carrying live steam are made extra heavy to provide for 150 lbs. steam pressure, and were tested and made tight under 300 lbs. cold-water pressure after being erected in place.

The exhaust piping contains no special features and is clearly shown in Figs. 11 and 12. A second header will be provided for the west row of engines similar to that for the row already in place, and a third header will be provided, running directly to the condenser and connected to all the engines on both sides. Any engine may then be run either condensing or non-condensing. Fig. 15 shows the de-

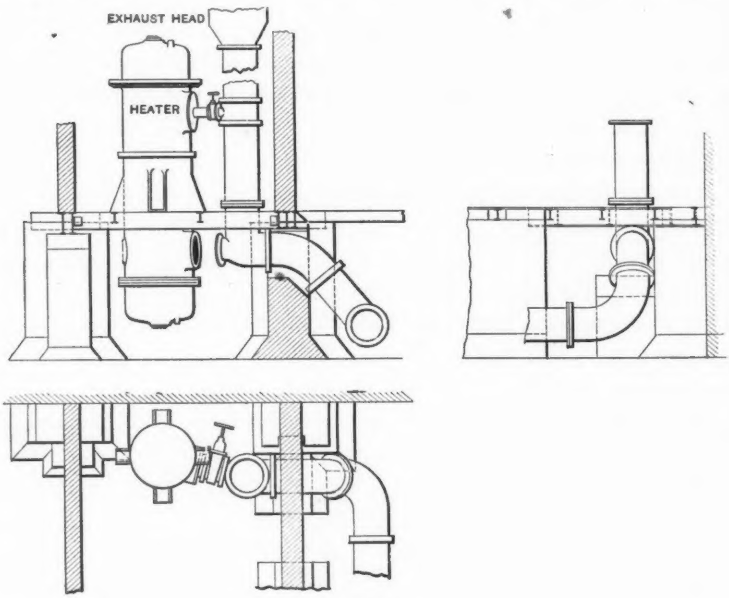

FIG. 15.

tails of the connection of the free exhaust to heater No. 2, and the details of the floor beam system in the north end of the pump room.

Fig. 16 shows the feed and blow-off lines. On the feed lines it will be seen that the loop system has again been employed. The mains make a complete closed loop in the center of the boiler-room, from which the boilers are fed on either side. This loop is fed at either end, the water to reach one end having to pass through the heaters and going directly to the other end. An inspection of the illustration

will show how any section of this system may be cut out without shutting down more than one boiler.

Although provision is made in this station for the switchboard and all the accompanying apparatus, the switchboard room of the old Twenty-ninth Street station has thus far been used, as it is advisable to have both boards in close communication while both stations are running and circuits frequently transferred from one station to the other.

The lead wires from the machines consist of lead-armored cables run in iron ducts directly from each dynamo to its panel on the dynamo board. On this board each alternator as well as each exciter has its own panel equipped with the customary appliances, including

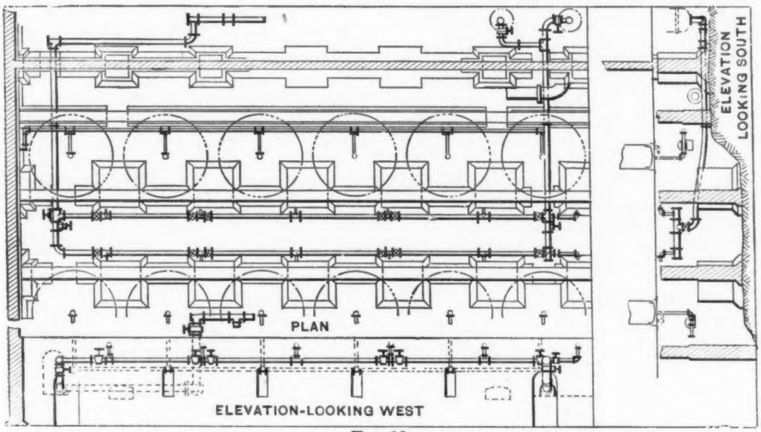

FIG. 16.

volt meter, ammeter, rheostat, fuse blocks, switches, etc. From each panel on this board connection is made to a separate pair of buss bars on the back and running the length of the feeder board, and here each circuit has a separate panel equipped with a volt meter, ammeter, continuous registering meters, etc. At a convenient height on each panel is situated a double-pole dynamo change-switch with the circuit leading out from the center and two flexible cables connected to each end. These cables can be plugged in on any pair of buss bars and a circuit transferred from one dynamo to another by a single throw of the switch. From the center of these switches the circuits run to a third board called the cable terminal board, where, after passing through fuse blocks and a second set of switches used for transferring any

circuit from its own panel to a spare panel provided in case it is desirable at any time to cut any feeder panel dead, connection is made to the ends of the cables, which extend down through the floor and out to the subways. The entire distribution system is underground, and occupies about 150 miles of ducts. The voltage is reduced to any desired pressure by means of converters placed in convenient locations, usually in vaults under the sidewalk. Continuous registering meters are employed to determine the amount of current consumed; they are of the Shallenberger type.

This station has been in constant operation since September 23d, 1895, when it was first started up, and the load on it has been continually growing heavier, as circuit after circuit has been cut over from the old system to the new. So far everything has operated in an entirely satisfactory manner, and none of the difficulties and annoyances usually incident to the starting up of a large plant have been experienced.

The author submits this paper with the belief that in this station are embodied a number of features somewhat unusual in central station design, and he will be pleased to discuss in more detail any special points which may be of interest to the Members of the Society.

Vol. XXII. MARCH, 1896. No. 3.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publication.

CONTENTS.

SOCIETY AFFAIRS.

PAPERS.

The Proceedings and Transactions will be sent to any subscriber at the rate of $10 per year. Postage will be added when sent to foreign countries.

American Society of Civil Engineers.

OFFICERS FOR 1896.

President, THOMAS C. CLARKE.

Vice-Presidents.

Term expires January, 1897:	*Term expires January*, 1898:
DESMOND FITZGERALD,	WILLIAM R. HUTTON.
BENJAMIN M. HARROD,	P. ALEXANDER PETERSON.

Secretary, CHARLES WARREN HUNT.

Treasurer, JOHN THOMSON.

Directors.

Term expires January, 1897:	*Term expires January*, 1898:	*Term expires January*, 1899:
WILLIAM H. BURR,	AUGUSTUS MORDECAI,	GEORGE A. JUST,
JOSEPH M. KNAP,	CHARLES SOOYSMITH,	WM. BARCLAY PARSONS,
BERNARD R. GREEN,	GEORGE H. BENZENBERG,	HORACE SEE,
T. GUILFORD SMITH,	GEORGE H. BROWNE,	JOHN R. FREEMAN,
ROBERT B. STANTON,	ROBERT CARTWRIGHT,	DANIEL BONTECOU,
HENRY D. WHITCOMB.	FAYETTE S. CURTIS.	THOMAS W. SYMONS.

Assistant Secretary, JOHN M. GOODELL.

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THE PRESIDENT OF THE SOCIETY IS *ex-officio* MEMBER OF ALL COMMITTEES.

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JOSEPH M. KNAP,	WILLIAM H. BURR,	T. GUILFORD SMITH,
HORACE SEE,	JOHN THOMSON,	ROBERT B. STANTON,
WM. BARCLAY PARSONS,	ROBERT CARTWRIGHT,	AUGUSTUS MORDECAI,
F. S. CURTIS,	DESMOND FITZGERALD,	DANIEL BONTECOU,
JOHN R. FREEMAN.	HENRY D. WHITCOMB.	CHARLES WARREN HUNT.

Special Committees.

ON UNIFORM STANDARD TIME:—Sandford Fleming, Charles Paine, Theodore N. Ely, J. M. Toucey, T. Egleston.

ON ANALYSIS OF IRON AND STEEL:—Sub-Committee of the American Society of Civil Engineers (of the International Committee on Standards for the Analysis of Iron and Steel, of which Prof. J. W. Langley is Chairman)—Charles B. Dudley, William Metcalf, Thomas Rodd, A. E. Hunt.

ON UNITS OF MEASUREMENT:—George M. Bond, William M. Black, R. E. McMath, George F. Swain.

The rooms of the Society are open from 9 to 17 o'clock each business day, except Saturday (when they are closed at 15 o'clock), and at other times on application to the Janitor.

HOUSE OF THE SOCIETY—127 EAST TWENTY-THIRD STREET, NEW YORK.

Vol. XXII. MARCH, 1896. No. 3.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

ERRATA.

PROCEEDINGS. VOLUME XXII.

Page 38, line 18, and page 47, line 15, for "Prof. Ricketts" read "Prof. Comfort."

Page 66, line 7, for "Binion, Julius" read "Binion, Joshua."

OF THE SOCIETY.

March 4th, 1896.—The meeting was called to order at 20 o'clock, President Thomas Curtis Clarke in the chair; Charles Warren Hunt, Secretary, and present, also, 65 members and 16 visitors.

Minutes of the meetings of February 5th and 19th, 1896, were adopted as printed in *Proceedings* for February, 1896.

Walter G. Berg, M. Am. Soc. C. E., moved the adoption of the following preamble and resolutions:

Whereas, Most comprehensive and valuable investigations into the properties of wood and tests of the strength of our commercial timbers have been carried on for a number of years in the Forestry Division of the United States Department of Agriculture, but have proceeded very slowly, and have from time to time been entirely discontinued on account of deficient appropriations; and

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Whereas, These investigations, as far as the results have been published, have already demonstrated that this work is tending towards a most needful and rational economy of our forest resources and desirable improvements in their use, resulting not only in a great saving to users of timber throughout the country, but especially offering a valuable guarantee for the proper safety of timber structures; and

Whereas, It is desirable to emphasize not only the value of these government timber tests to the engineering profession and to all technical and industrial interests, but also the importance of publishing the results of tests as promptly as possible; therefore

Be it Resolved, That the sense of this meeting of the American Society of Civil Engineers is that our representatives in Congress be requested to make liberal appropriations from time to time for the continuance and more rapid advance of this work;

Resolved, Further, that we particularly request, at the present time, the prompt and favorable consideration of Senate Bill No. 1214, introduced December 27th, 1895, entitled "A bill to appropriate funds for investigations and tests of American timber";

Resolved, Further, that these resolutions be regularly transmitted to the President of the Senate, the Speaker of the House of Representatives, the Secretary of Agriculture, the Chairman of the Committee on Forestry and Agriculture of the Senate, and the Chairman of the Committee on Forestry and Agriculture of the House of Representatives.

By an amendment to Mr. Berg's motion, offered by Charles Macdonald, M. Am. Soc. C. E., the whole matter was referred to the Board of Direction, with a request that it report at a subsequent meeting.

A paper entitled "The Strength of Pillars—An Analysis," was presented by Leopold Eidlitz, Esq. Correspondence on the subject from George S. Morison, Past-President Am. Soc. C. E., was read by the Secretary, and the paper was discussed orally by Messrs. Walter G. Berg, George H. Thomson, Henry S. Prichard, Oscar Lowinson and Leopold Eidlitz. Upon motion of Charles Macdonald, M. Am. Soc. C. E., a vote of thanks was passed to Mr. Eidlitz for this paper.

Ballots were canvassed and the following candidates were declared elected.

As Members.

Robert Morris Clayton, Atlanta, Ga.
Martin Luther Gardner, Newark, N. J.
Fred. Morley, Lafayette, Ind.
David Abell Reed, Duluth, Minn.
Alfred Varley Sims, Iowa City, Iowa.
George Attwater Tibbals, Brooklyn, N. Y.

As Associate Members.

Robert Hazlett, Wheeling, W. Va.
Francis Henry, New York City.
Cary Talcott Hutchinson, New York City.

WARREN RUE KINSEY, Newark, N. J.
DOMINIK LINDENTHAL, Boston, Mass.
JOHN CHRISTIAN OSTRUP, Chicago, Ill.
ALVAH HORTON SABIN, Long Island City.

The Secretary announced the election by the Board of Direction on March 3d, 1896, of the following candidates:

As ASSOCIATE.

WILLIAM PENDLETON PALMER, Pittsburg, Pa.

As JUNIORS.

GEORGE LANGDON BALLOU, Buffalo, N. Y.
PERCY CANFIELD BARNEY, Brooklyn, N. Y.
WILLIAM WHITLOCK BRUSH, Brooklyn, N. Y.
THOMAS JENKS CARLILE, Philadelphia, Pa.
THOMAS CURTIS CLARKE, Jr., New York City.
NOAH CUMMINGS, Easton, Pa.
LESTER ROBINSON GIFFORD, New York City.
WALTER GRANT PENFIELD, New Haven, Conn.

The Secretary announced the death of Charles L. Colby, elected Fellow July 31st, 1883; died February 26th, 1896.

The Secretary stated further that in the matter of the design for the new Society House, it had been decided to institute a competition in which all architects connected with the Society might participate, together with a limited number of architects not connected with the Society, to whom special invitations would be issued. It was announced that a circular giving the conditions of the competition would be sent to any member on application to the Secretary.

Adjourned.

Wednesday, March 18th, 1896.—The meeting was called to order at 20.15 o'clock, President Thomas Curtis Clarke in the chair; Charles Warren Hunt, Secretary, and present, also, 60 members and 13 guests.

A paper entitled "The Twenty-eighth Street Central Station of the United Electric Light and Power Company," was presented by H. W. York, Jun. Am. Soc. C. E., and discussed by Messrs. E. E. Russell Tratman, George R. Hardy, Charles E. Emery and the author.

The Secretary announced the death of Andrew Jackson Post, elected Member November 1st, 1871; died March 12th, 1896.

The Secretary stated that the discussion on the paper by Leopold Eidlitz, Esq., presented March 4th, 1896, would close on April 15th, 1896, and that the discussion on Mr. York's paper would close May 1st.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

March 3d, 1896.—Eight Members present.

Under Article VII, Section I, of the Constitution, the territory occupied by the membership was divided into seven geographical districts for the purposes of the Nominating Committee.*

Reconsideration Ballots were canvassed.

Applications were considered and other routine business transacted.

One candidate as Associate and eight as Juniors were elected.

Adjourned.

ANNOUNCEMENTS.

MEETINGS.

Wednesday, April 1st, 1896, at 20 o'clock, a regular meeting of the Society will be held, at which a paper will be presented by M. Lewinson, M. Am. Soc. C. E., entitled, "The Transverse Strength of Beams as a Direct Function of the Tensile and Crushing Stresses of Material." This paper is published in this number of *Proceedings.*

Wednesday, April 15th, 1896, at 20 o'clock, a regular meeting of the Society will be held. The paper to be presented is by Charles Sooysmith, M. Am. Soc. C. E., and is entitled, "Concerning Foundations for Heavy Buildings in New York City." It is printed in this number of *Proceedings.*

Correspondence on the above papers is invited from those who cannot be present at the meetings, and may be sent by mail to the Secretary. The papers, with discussion, will be published in *Transactions.*

DISCUSSIONS.

Discussion on the paper by Leopold Eidlitz, Esq., entitled, "The Strength of Pillars—An Analysis," which was printed in *Proceedings* for February, 1896, will close April 15th, 1896.

Discussion on the paper by H. W. York, Jun. Am. Soc. C. E., entitled, "The Twenty-eighth Street Central Station of the United Electric Light and Power Company," which was printed in the same number of *Proceedings,* will close May 1st, 1896.

NOMINATING COMMITTEE.

Under Article VII, Section 1, of the Constitution, the Board of Direction has divided the territory occupied by the membership into seven geographical districts, for the purposes of the Nominating Committee:

District No. 1.—The territory within 50 miles of the Post Office in the City of New York.

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* See Announcements.

District No. 2.—The remainder of the States of New York and New Jersey and Canada.

District No. 3.—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island and Connecticut, and all foreign countries.

District No. 4.—Pennsylvania, Delaware, Maryland and District of Columbia.

District No. 5.—Michigan, Ohio, Indiana, Illinois and Wisconsin.

District No. 6.—Minnesota, Iowa, Missouri, Kansas, Nebraska, North Dakota, South Dakota, Washington, Montana, Wyoming, Idaho, Colorado, Utah, Oregon and Nevada.

District No. 7.—Virginia, West Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Louisiana, Florida, Texas, Tennessee, Kentucky, Indian Territory, Oklahoma, New Mexico, Arizona, Arkansas and California.

PAPERS.

The system of publication recently adopted provides that papers shall be printed in *Proceedings* prior to the date of their presentation to the Society. It is desirable, under this rule, that at least three weeks should intervene between the publication and presentation of each paper, thus giving each member opportunity to contribute his views in writing to the meeting. Up to the present time the number of papers received and accepted for publication has not been sufficient to accomplish this. Time is always necessary for the examination and acceptance of a paper by the Publication Committee, as well as for proper care in preparation of the text, and particularly of the illustrations. The purpose of this note is to call the attention of each person connected with the Society to the fact that he should not lose sight of the promise in the obligation he has signed, to "aid the objects of the said Society by furnishing papers and discussions," but should send in promptly accounts of any interesting, novel or instructive work or investigations conducted under his supervision. This is necessary if the aims of the Society, as stated in Article I of the Constitution, are to be carried out. A note to the Secretary calling attention to interesting subjects for papers, with an indication of the source from which they should be received, will also be of assistance in this matter. During 1895 less than 2% of the membership contributed papers, and less than 7% discussed them. It is submitted that an increase in these figures would be of great advantage to the profession and to the Society, and it is hoped that efforts will be made by every one to assist the officers of the Society in this direction.

The last number of *Proceedings* before the next Annual Convention will be issued on May 27th, 1896, and under the rule all papers intended for presentation at the Convention should be therein published. To accomplish this they must be in the hands of the Secretary on or before May 1st.

MEMOIRS.

The attention of Members is called to page 150 of the List of Members recently issued. Here will be found the names of deceased members of the Society, the grade of their membership, date of death, and volume and page of *Proceedings* where memoirs have been published. It will be seen that of the 314 names on the list, 89 have no reference to a memoir, or, in other words, no account of the life and work of 28% of the deceased members of the Society is recorded in its publications.

It is hoped that each member will scan this list and supply such missing memoirs as he can prepare, or contribute any information which will aid the Secretary in their preparation.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

			Date of Membership.
CLAYTON, ROBERT MORRIS	City Engineer, Atlanta, Ga.		March 4, 1896
GARDNER, MARTIN LUTHER	58 Elizabeth Ave., Newark, N. J.	Assoc. M.	Sept. 2, 1891
		M.	March 4, 1896
MAYNE, CHARLES	Kiangse Road, Shanghai, China		Jan. 1, 1896
MCHENRY, EDWIN HARRISON	Chf. Eng. N. P. R. R., St. Paul, Minn		Feb. 5, 1896
SIMS, ALFRED VARLEY	Prof. Civ. Eng., Univ. of Iowa, Iowa City, Iowa		March 4, 1896
TIBBALS, GEORGE ATTWATER	148 Milton St., Brooklyn, N. Y.	Jun.	May 2, 1888
		M.	March 4, 1896

ASSOCIATE MEMBERS.

GRANTHAM, HERBERT THOMAS	1527 Poplar St., Philadelphia, Pa	Feb. 5, 1896
HAZLETT, ROBERT	Brown & Hazlett, Wheeling, W. Va.	March 4, 1896
LINDENTHAL, DOMINIK	1398 Tremont St., Boston, Mass	March 4, 1896
MONTONY, LIBERTY GILBERT	Brown Hoisting and Conveying Machine Co., Cleveland, Ohio	Feb. 5, 1896
OSTRUP, JOHN CHRISTIAN	444 North Clark St., Chicago	March 4, 1896
SABIN, ALVAH HORTON	Box 85, Long Island City, N. Y.	March 4, 1896

ASSOCIATE.

QUINCY, CHARLES FREDERICK	Treasurer Q. & C. Co., Chicago	Feb. 4, 1896

JUNIORS.

ADEY, WILLIAM HENRY	Swarthmore, Pa	Feb. 4, 1896
BRUSH, WILLIAM WHITLOCK	395 Jefferson Ave., Brooklyn, N. Y.	March 3, 1896
CARLILE, THOMAS JENKS	4215 Chestnut St., Philadelphia, Pa.	March 3, 1896
DIEHL, GEORGE CONRAD	Care Div. Eng. State Canals, Syracuse, N. Y.	Feb. 4, 1896
SELTZER, HARRY KENT	Care Combination Bridge Co., Sioux City, Iowa	Feb. 4, 1896
SMITH, WALTER TENNY	424 Warren Ave., Chicago.	Feb. 4, 1896

CHANGES AND CORRECTIONS.

MEMBERS.

ARGOLLO, M. T	Director and Chf. Eng., Bahia Ext. R. R., Alagoinha, Bahia, Brazil.
CROSBY, WILSON	303 Hammond St., Bangor, Me.
DAVIS, C. E. L. B	89 Flood Bldg., San Francisco, Cal.
GARDNER, G. C	235 New Jersey Ave., Washington, D. C.
HEUER, WILLIAM H	Corps of Engrs., U. S. A., Custom House, Cincinnati, O.
HINCKLEY, J. F	952 Laurel St., St. Louis, Mo.
HISLOP, JOHN	Box 1225, Salt Lake City, Utah.
LA CHICOTTE, H. A.	150 Nassau St., New York City.
LAWLOR, F. D. H	Woodstock, Carleton Co., N. B.
McDONALD, JOHN A	Res. Eng., Harbor Works, Fremantle, Western Australia.
PRICE, W. G	2020 State St., Chicago, Ill.
PRINCE, GEORGE T	Eng. Water Co., Omaha, Neb.
ROWE, S. M	186 North Green St., Chicago, Ill.
SAMPLE, J. H	Room 402, Society for Savings Bldg., Cleveland, Ohio.
SEAMAN, H. B	45 Broadway, New York City.
SEARS, A. F	Portland, Ore.
SHAW, G. W	Louisville, Ky.
STANTON, R. B	P. O. Box 1225, Salt Lake City, Utah.
STONE, E. H	Chf. Eng. Const. East Indian Ry., Allahabad, India.
TOMLINSON, SAMUEL	Municipal Eng., Singapore, Straits Settlements.
WROTNOWSKI, A. F.	Director Harbor Works, Vera Cruz, Mexico.

ASSOCIATE MEMBERS.

Erlandsen, O....................136 Liberty St., New York City.
Gubelman, F. J..................792 Montgomery St., Jersey City, N. J.
Hawley, W. C....................Care Water Dept., Atlantic City, N. J.
Howard, C. P....................1400 Grove Ave., Richmond, Va.
Rapp, J. V. B....................136 Liberty St., New York City.

JUNIORS.

Beugler, E. J....................162 Norman St., Bridgeport, Conn.
Boatrite, J. E....................129 West 13th St., New York City.
Farley, Philip P................Care Ashmead & Hackney, Atlantic City, N. J.
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Post, Andrew Jackson...........Elected Member Nov. 1st, 1871; died March 12th, 1896.

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Present Phosphorus Determinations in Steel.
Southern Magnetites.
Specifications for Steel Rails of Heavy Section Manufactured West of the Alleghenies.
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1896. MARCH. No. 3.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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PAPERS.

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CONTENTS:

THE TRANSVERSE STRENGTH OF BEAMS AS A DIRECT FUNCTION OF THE TENSILE AND CRUSHING STRESSES OF MATERIAL.

By M. LEWINSON, M. Am. Soc. C. E.

TO BE PRESENTED APRIL 1ST, 1896.

The theory of the transverse strength of beams of any shape is based on the assumption that the intensity of fiber resistances is directly proportional to the respective distances of the fibers from an axis called neutral, and that the sum of all the fiber stresses above the axis is equal to the sum of those below. Hence the neutral axis must pass through the center of gravity of the beam section, and, as a consequence, the maximum fiber stress in beams of unsymmetrical section is at those extreme fibers which are most distant from the neutral axis. A further consequence of this theory is that no matter what

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

may be the material and section of the beam, its transverse strength in regard to the neutral axis is the same, whether the extreme fibers parallel to this axis are subjected to the one or to the opposite kind of forces. It is also maintained that beams of a material whose resistances to crushing and rupture are not equal must invariably break first at the weakest fibers.

It is well known how unsatisfactory are the results of the above theory, which are substantiated by experiments in only a few cases. It is known, for instance, that cast-iron beams of angle or T section are stronger when the compression forces are acting in the webs instead of in the flanges, and that in breaking timber beams the fibers in tension rupture before the compression fibers are affected, although the tensile strength of the wood may be four or five times as great as its compressive strength. This last phenomenon, as also some experiments made on beams of different materials, leads the author to the conclusion that the lower and upper fibers of beams under transverse breaking load are strained to their maximum fiber resistances. This is the fundamental principle on which the following theory is based.

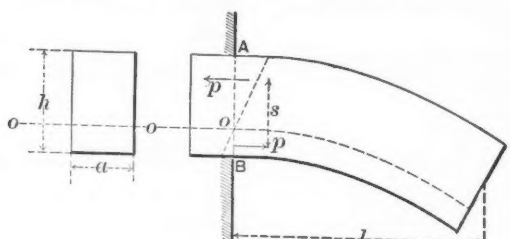


FIG. 1.

Let Fig. 1 represent a rectangular beam fixed at one end and bent, say to the breaking point, by a force W attached at the other end. The weakest place of such a beam is at the plane $A\,B$, which, under the influence of the moment $W\,l$, will rotate around a certain axis O. This rotation is opposed by $p\,s$, consisting of a leverage s and the sum of all the fiber resistances p, above or below the axis O, along the plane $A\,B$. The question arises what is the intensity of p, and what is the relation and position of s to the height of the beam section and its rotation axis respectively? Let x denote the distance of the rotation axis from the lower compressed fibers, the distance of the tension fibers will be $h - x$. The fibers at A are strained to their utmost capacity, say with a tensile stress T pounds per square inch, and the fibers at B are also strained to their utmost capacity with a crushing stress of C

pounds per square inch. These forces, being maximum at the extreme fibers, diminish in intensity toward each other in a direct ratio to the distances of the fibers from the rotation axis, where they meet and are zero. Therefore they can be represented graphically as areas of triangles, the bases of which are $T\,a$ and $C\,a$, and the heights x and $h - x$ respectively. The sum of all the forces represented by each of the triangles being the forces of a couple, they must be equal to each other, i. e.,

$$\tfrac{1}{2}\,C\,a\,x = \tfrac{1}{2}\,T\,a\,(h - x).$$

From this equation it will be found that:

$$x = \frac{T}{C+T} \cdot h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

the fundamental expression for the position of neutral axis for rectangular beams. Making $C = T$ in the above formula, as is nearly true in wrought iron, x will equal $\frac{1}{2}\,h$ and coincide with the axis through the center of gravity. For cast iron (tension, 20 000; compression, 100 000), $\frac{C}{T} = 5$; therefore $x = \frac{1}{6}\,h$. For yellow pine, $\frac{C}{T} = \frac{1}{2}$ and $x = \frac{2}{3}\,h$.

The foregoing shows that the position of the neutral axis in a rectangular beam is nearer to those extreme fibers whose resistance is greatest.

It is further evident that the resultant of all the fiber resistances will act at the center of gravity of the triangle representing them, i. e., at one-third of the height of the triangle, or at two-thirds of the distance from the apex O; therefore $s = \frac{2}{3}\,x + \frac{2}{3}\,(h - x) = \frac{2}{3}\,h$, or the leverage of a couple in a rectangular beam is always two-thirds of its height, and its position in the section of the beam is dependent on the position of the neutral axis. This proposition is identical with the general mechanical law that the resultant fiber resistances act at the antipoles of the neutral axis in regard to the ellipse of gyration in the parts of the beam section above and below the axis. As will be seen later this general mechanical law is also true in this new theory for all sections, except that the neutral axis does not always coincide with the axis through the center of gravity.

Having found the magnitude and position of p and s, it is now possible to calculate the transverse strength of a beam, knowing only the crushing and tensile resistances of any material.

Referring again to Fig. 1:

$$p = \tfrac{1}{2}\, C\, a\, x = \tfrac{1}{2}\, T\, a\, (h - x)$$

and substituting in this equation the value for

$$x = \frac{T}{C + T}\, h,$$

it will be found:
$$p = \tfrac{1}{2}\, \frac{C\, T}{C + T}\, a\, h$$

and the moment will be:

$$M = p\, s = \tfrac{1}{3}\, \frac{T\, C}{C + T}\, a\, h^2 \quad \text{.................. (2)}$$

For $C = T$ the moment will be $M = \frac{1}{6}\, C\, a\, h^2 = p\, s$ the familiar formula, in which $\frac{1}{6}\, a\, h^2$ is the moment of resistance of a rectangular beam by the common theory. For glass* it has been found that $C = 30\,150$ lbs., and $T = 2\,560$ lbs., and a 1-in. square bar 12 ins. between supports broke with a center load of 262 lbs. Substituting the values for C and T in formula (2), and noting that $h = a = 1$ in. and $l = 12$ ins., $3\, W\, l = 786.5$, or the theoretical center breaking weight $W = 262\frac{1}{4}$ lbs., which is identical with the one found by experiment.

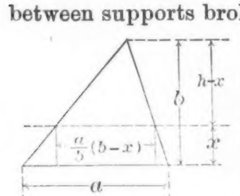


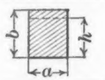
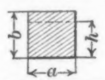
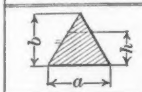
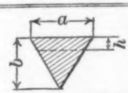
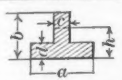
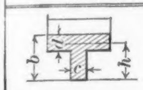
FIG. 2.

For cast iron the author made a series of experiments on beams of various cross-sections, the results of which are appended in Table No. 1. Before explaining these it is desirable to show the derivation from this theory of formulas for other than rectangular shapes.

Let Fig. 2 represent a section of a triangular beam, having a base a, and height b. At the apex the fibers are compressed with a crushing stress C per square inch, and the fibers at the base are stretched with a tensile stress T per square inch. If the neutral axis passes through the triangle parallel to and at distance x from the base, the sides of the triangle will cut from the neutral axis a distance $\frac{a}{b}(b - x)$, and the difference between a and $\frac{a}{b}\,(b - x)$ will be $\frac{a}{b}\, x$. Knowing also that the sum of all the intensities in a triangle in regard to its base is

* See "Strength of Materials," by Thomas Box.

TABLE No. 1.—RESULTS OF EXPERIMENTS ON BEAMS OF VARIOUS CROSS-SECTIONS.

I	II	III				IV	V		VI	VII	VIII		IX
Section of Beam		DIMENSIONS				Clear Span	Ultimate Strength per. sq. inch		Distance of neutral Axis h	Leverage of Couple	Center Breaking Load in Pounds		Remarks
		a	b	c	d		Tensile	Crushing			By Test	By Rule	
	I	1.011″	2.02″			5′0″	19620	81697	1.6288″	1.34667″	1316	1450	Broke in center
	II	0.99	2.00			"	18772	79491	1.6179	1.33333	1165	1323	Broke $2\frac{3}{4}$″ from cen.
	III	1.012	2.02			"	21560	83006	1.6035	1.34667	1446	1585	Broke in center
	I	1.836	1.862			4′0″	17676	75954	1.51048	1.24133	2400	2535	Broke $1\frac{1}{4}$″ from cen.
	II	1.860	1.865			"	17270	75590	1.51466	1.25333	2321	2519	Broke $\frac{1}{2}$″ from cen.
	III	1.865	1.861			"	17538	74586	1.50672	1.24067	2501	2429	Broke $\frac{1}{2}$″ from cen.
	I	2.02	2.04			5′0″	21680	81828	0.91612	1.19958	1346	1364	Broke $1\frac{3}{4}$″ from cen.
	II	2.03	2.03			"	22308	77256	0.87962	1.18639	1386	1348	Broke $\frac{1}{4}$″ from cen.
	III	2.04	2.09			"	25033	90451	0.92188	1.22513	1725	1640	Broke in 2 places $4\frac{3}{4}$″ from center
	I	2.00	2.05			"	18430	75532	0.14717	1.05013	665	760	Broke $1\frac{5}{8}$″ from cen.
	II	2.04	2.06			"	22944	89678	0.15421	1.05636	826	969	Broke $2\frac{15}{16}$″ from cen.
	III	2.03	2.05			"	23204	88253	0.15719	1.05188	860	962	Broke $\frac{1}{4}$″ from cen.
	I	4.06	3.00	0.425	0.350	"	27555	115633	1.413260	2.2399	4770	5822	Broke $\frac{1}{2}$″ from cen.
	II	4.115	3.05	0.455	0.370	"	26723	98806	1.312192	2.2422	4520	5839	Broke in center
	III	4.155	3.05	0.430	0.360	"	27041	110475	1.383354	2.2643	4990	5975	Broke in center
	I	4.160	3.10	0.440	0.400	"	25816	115498	3.0217	1.9466	2400	2441	Broke $\frac{5}{8}$″ from cen.
	II	4.160	3.05	0.420	0.365	"	23841	109616	2.9789	1.8906	2220	2042	Broke in center
	III	4.150	3.04	0.420	0.370	"	21420	102243	2.97124	1.87753	2080	1826	Broke $\frac{3}{4}$″ from cen.

one-third of the area of the triangle multiplied by the unit of resistance, the following equation may be written :

$$\frac{1}{6}\,C\,\frac{a}{b}\,(b-x)^2 = \frac{1}{2}\,T\,a\,x - \frac{1}{6}\,T\,\frac{a}{b}x^2 \ldots\ldots\ldots\ldots\ldots (3)$$

From which $x = \frac{b}{2\,(C+T)}\left[2\,C + 3\,T \pm \sqrt{(8\,C+9\,T)\,T}\right] \ldots\ldots (4)$

If the bar is reversed so that the crushing stress C acts at the base and the tensile stress T at the apex of the triangle, it is only necessary to substitute in formula (4) T for C, and C for T, to get the value for x, which is :

$$x = \frac{b}{2\,(C+T)}\left[2\,T + 3\,C \pm \sqrt{(8\,T+9\,C)\,C}\right]$$

If C equals T, x will be 0.219224 b. Having determined the position of the neutral axis and substituting the value for x in formula (3), three distinct quantities are obtained. Since the resultant of the intensities in such a triangle finds its point of application on the line drawn from the apex to the center of the base in a perpendicular distance of one-half the height of the triangle from the base, it is easy to calculate the leverage of the couple. For instance, if $x = s_1$; $b - x = s_2$; $\frac{1}{6}\,C\frac{a}{b}\,(b-x)^2 = p$; $\frac{1}{2}\,T\,a\,x = p_1$; $\frac{1}{6}\,T\,\frac{a}{b}\,x^2 = p_2$; then the moment of resistance will be : $p\,s = \frac{1}{2}\,p\,s_2 + (\frac{2}{3}\,p_1 - \frac{1}{2}\,p_2)s_1$ in which $p_1 - p_2 = p$ and $\frac{\frac{2}{3}\,p_1 - \frac{2}{3}\,p_2}{p_1 - p_2}\,s_1 = s_0$ or $p\,s = p\,(\frac{1}{2}\,s_2 + s_0)$; s_0 and $\frac{1}{2}\,s_2$ are measured from the neutral axis, and they are dependent on the position of this axis or on C and T.

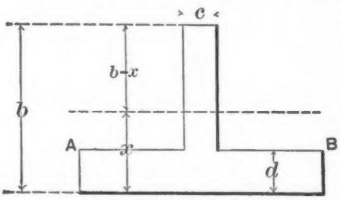


FIG. 3.

The neutral axis in a beam of the section shown in Fig. 3 may pass through the web, or through the flange, or through the edge $A\,B$ of the flanges, i. e., the sum of the intensities in the web may be greater, smaller, or equal to the intensities in the flange. Only the first two cases will be considered, as the third case needs no explanation.

First Case.—Let the neutral axis pass through the web of the beam, and let C be the crushing stress per square inch at the top of web, and T the tensile stress at the bottom edge of the flange; then the unit

of tensile resistance at $A\ B$ will be : $T\frac{x-d}{x}$, and the following equation for x may be written :

$$\tfrac{1}{2}\ C c\ (b - x) = \tfrac{1}{2}\ T a x - \tfrac{1}{2}\ T\ (a - c)\ \frac{(x-d)^2}{x} \dots\dots\dots (5)$$

$$\text{or } x^2 + \frac{2\ T\ (a-c)\ d - C b c}{c\ (C+T)}\ x - \frac{T\ (a-c)}{c\ (C+T)}\ d^2 = 0$$

Second Case.—Let Fig. 4 represent the beam section when the neutral axis passes through the flange. If C denotes the crushing stress per square inch at the top edge of the flange, and T the tensile stress at the bottom edge of the web, then

$$\tfrac{1}{2}\ C a\ (b - x) = \tfrac{1}{2}\ T c x + \tfrac{1}{2}\ T\ (a - c)\ \frac{[x - (b-d)]^2}{x} \dots\dots\dots (6)$$

$$\text{or } x^2 - \frac{C a b + 2\ T\ (a-c)\ (b-d)}{a\ (C+T)}\ x + \frac{T\ (a-c)\ (b-d)^2}{a\ (C+T)} = 0$$

The determination of the couple leverage s is similar to that in the case of the triangular shape, noting only that for each part of the beam the sum of intensities acts at two-thirds of their heights from the axis. In a similar way, x and s may be found for any shape.

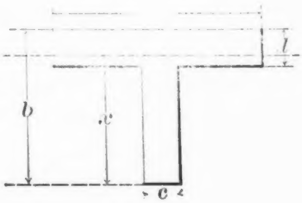


FIG. 4.

Table No. 1 has been prepared according to this theory. Three test pieces for each experiment have been cast from ordinary foundry iron, a mixture of about 50% 2 X Low Moor pig, and about 50% stove and machine scrap. Each specimen with a corresponding mark in column 2 was cast from the same ladle. All the specimens were broken in a 100 000-lb. Riehle testing machine, and tensile and crushing specimens prepared from the broken pieces. For the tensile tests the rectangular and triangular bars were turned down to about $\frac{7}{8}$ in. diameter for a distance of 6 ins., and from the **T** bars flats were cut about 0.4 x 0.8 ins. for a distance of 6 ins. For the crushing tests, specimens of about $\frac{3}{4}$ x $\frac{3}{4}$-in. base and $1\frac{1}{2}$ ins. high were cut from the rectangular and triangular bars; and pieces of about 0.4 x 0.4 in. base and about 0.8 in. high from the **T** bars.

While these tests are not all that is to be desired, they nevertheless serve to confirm the theory here presented. It at least clears up to the student of mechanics the difficulties of the moment of resist-

ance and shows that this moment is not always the same in the same beam in regard to the neutral axis. In many text books it is stated that to find the moment of resistance of an unsymmetrical section, divide the moment of inertia for safety by the greater distance of extreme fibers from the neutral axis, implying that the smaller distance would be also correct. This is clearly not true, because from the manner of derivation of the moment of inertia the greater value must be used, and the value so found multiplied by the stress coefficient.

In column 8 of Table No. 1 are given the center breaking loads as found by tests and by calculations, according to the theory here advanced. They correspond fairly well with each other except in the T bar section with the web up, where undoubtedly the wrinkling and buckling stresses added materially to the destruction of the material. The longitudinal and vertical shearing stresses were also not taken into account in these calculations. From equations (1), (3), (5) and (6) it is readily seen that the value of x or the position of the neutral axis does not change if multiples of T and C are taken, showing that these formulas are also correct in case the working stresses are taken in place of C and T. Equation (2) shows also that having two of the three values, C, T, and W, the third can be determined. For instance, a 1-in. square bar of brass, 12 ins. between supports, broke with a center load of 1 150 lbs. The tensile strength of this metal was found to be 17 970 lbs. per square inch. Substituting these values for T and W in equation (2), the value of C is found to be 24 408 lbs. per square inch.

This theory not only gives results more nearly in accord with those found by experiment than the common theory, but gives also a conception of the stresses working in a beam. In designing, it permits the choice of the most appropriate cross-section and material for any given purpose on a rational basis. In closing the author may add that he hopes a better and more extensive series of experiments bearing on this subject will be made on materials more homogeneous than those used for illustration in this paper.

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CONCERNING FOUNDATIONS FOR HEAVY BUILDINGS IN NEW YORK CITY.

By CHARLES SOOYSMITH, M. Am. Soc. C. E.

TO BE PRESENTED APRIL 15TH, 1896.

As an introduction to what follows, it would seem well to describe briefly the chief conditions met under the surface in the parts of New York City where the high buildings recently constructed and proposed are situated. To this end a map of the city below Twenty-third Street is given in Fig. 1, which shows the principal topographical features of that territory before it was built upon. The dotted portions near the shore line show the made land, which it will be noticed is generally from one to two blocks in width. This map shows that Broad Street to above Exchange Place and Maiden Lane to Nassau Street occupy what were formerly inlets from the East River, and that there were ponds east and north of City Hall Square. There seems to have been a natural waterway practically all the way from the North River following about the line of Canal Street and into Collect Pond, and from thence to the East River near Chambers Street. Notice should be taken also of the location of Minetta Stream, which was formed

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

near the present junction of Eleventh Street and Sixth Avenue. This stream flowed through what is now Washington Square and into the Hudson a little below Houston Street. The lines indicating elevations must not be allowed to mislead; in many cases the comparatively elevated portions are land made by the processes of Nature in comparatively recent times, it being rather the exception in the lower part of the island to find other than a drifted or deposited material within the distance below the surface at which the foundations of buildings are usually built. This upper material is mud, silt, sand, usually from fine to very fine, and sometimes gravel. The hard stratum below it, where not rock, is generally an exceedingly firm and compact surface of silt, clay and gravel containing stones of various sizes, which is generally called hard-pan. This is so hard that, in reports on the borings taken to ascertain the nature of the underground material about the city, it has generally been referred to as rock. The so-called bed-rock in the profile prepared for the proposed tunnel road in Broadway is this material; in all probability, in lower Broadway. In its natural condition in place it is so hard that for all the weights that can come on it through the construction of buildings it may be considered absolutely unyielding. It cannot be dug up except by pick or chisel, and in large excavations can be best loosened by blasting. It may be well to state here that in the case of the Manhattan Life Insurance Building, the weight of which is borne on fifteen caissons proportioned to carry a pressure at their bases of 10.8 tons per square foot, some of them rest on solid rock and some on the compact stratum mentioned, and that not the slightest settlement can be discovered. As to its safe bearing capacity, there can be no question but that it is well in excess of what under the present building law may be put upon it by means of a concrete base, 150 lbs. per square inch or 10.8 tons per square foot.

As the thoughtful engineer views the building methods prevailing to-day, it would seem to him that there is perhaps no kind of construction where the force of habit has so disastrously hampered a proper and quick readjustment to new conditions. Buildings of the heights usual until recently seldom put upon the earth supporting them weights greater than 3 or 4 tons per square foot, and generally much less than this. The weights were distributed and spread without difficulty by the common methods that had always been used. Of

course there was occasionally some particular case, sometimes treated in an exceptional manner, but these were never important or numerous enough to bring about any radical change, either in the general carelessness with which the matter of foundations of buildings was considered,

FIG. 1.

or rather not considered, or in the method of constructing them. Nor was this necessary, because the earth held reasonably well the buildings built upon it, and, too, the cost and probable life of the buildings did not warrant a greater expenditure upon the foundations. The

weight upon the soil did not compress it to such a degree as to cause serious settlement, nor did it put the material under a pressure which would press it outward or upward if given an opportunity by a near-by excavation. With the sudden doubling of the usual height of buildings, and the consequent great increase of weight, the old foundation methods became, in many cases, entirely inadequate. If pursued, serious settlement was invited from overloading, and the danger of letting down the underlying material by lateral flow became considerable. In fact, the problem of foundations for a heavy building, where they are not carried to rock or hard-pan, has now become (and this fact seems to be strangely overlooked) one very largely of what vent may be given for the underlying material by excavations in the vicinity. It is not sufficient that the weight put upon the soil should not be so great as to cause serious settlement. Under the conditions existing this is not generally difficult, but the material must not be put under a pressure that will cause it to squeeze out from below in case an opportunity is afforded by deep excavations nearby. It will become apparent ere long that the erection of heavy buildings resting upon sand or soil, which they unduly overload, without carrying their foundations on piles or to solid material, has in many cases worked a serious wrong to owners of the adjoining lots, besides being itself a short-sighted economy, because of trouble and lessened value of the buildings so built. For instance, the author knows of one building of great weight, a very excellent and costly structure with a carefully built foundation, which, however, rests simply upon the fine sand into which it has settled slightly. This settlement, as was anticipated, has been uniform and has caused no damage, but the owners are aware of the danger of serious or disastrous settlement that may take place from the operations of putting in foundations of buildings in the neighborhood, even though at a considerable distance from them, for at no great depth below their footings there is material, if it be like that revealed by the nearby operations, which would be likely to squeeze out under the existing pressure, if given a vent, especially if at the same time there is any exciting cause from jarring or pumping. The shoring and underpinning of such a building, while possible, would be vastly more difficult and costly than for a building of but a few stories' height. It would, for instance, cost probably more than $100 000 to care properly for the building in question when the property adjoin-

ing is built upon, unless the height of the new building were kept considerably below what would now be the height of the most suitable improvement of the property. Under the present building law, when a structure is built alongside another and this latter has its foundations not less than 10 ft. below the street surface, the responsibility and cost of caring for the old building must be borne by the owners of the new adjoining one. Thus in the case just cited, when the property alongside the building mentioned is adequately improved, the builders have to grapple with the problem of supporting and probably building a new foundation under this building. Thus the fact that this building, while conforming to the building laws, has put the soil beneath it under unusually great pressure, will cost the owners of the adjoining lots at least $100 000, beside any damage that they may cause the old building. The question very forcibly presents itself, whether in the absence of specific statutes on the subject, the common law cannot and should not be invoked to prevent any owner from putting the soil beneath a new building under such unusual pressure that it is under dangerous tendency to squeeze laterally and thus materially limit his neighbor's future improvement, or else put him under great additional expense in carrying it out. In equity he should certainly be required so to use his own lot as not to injure that of his neighbor. It will be strange if this matter does not soon come up for consideration.

Where soils are overloaded there is extraordinary potency in slight vibration to cause settlement where the conditions are favorable. Hoisting engines are frequently found to be exciting causes in producing unequal settlement in the absence of unequal loading. In one case in lower New York where a very massive and well-built structure resting upon gravel and sand cracked after it had been in use a considerable time, the only new condition introduced to which it seemed possible to attribute the settlement manifested was pumping clear water from a nearby driven well. It seemed reasonable to assume that the water flowing through the sand made possible a slight readjustment of the particles which settled into closer union under the vibration of the machinery in the building.

A most interesting thing often shown by the settlement of buildings is the frequency of movement of the entire mass of soft material in the vicinity of rivers. There is a locality in New York City where there is

good reason to believe such a motion to be taking place. For instance, a certain large and well constructed building resting upon a well designed pile foundation, and where the piles were driven 40 or 50 ft into the silt, started to settle, probably before it was completed; at any rate, it settled from almost nothing at the end farthest from the river to some 2 ft. at the end nearest the river, making a practical wreck of part of the structure. This building was some 200 or 300 ft. from the river. An examination of the bulkhead wall showed that the piers had apparently acted as buttresses to hold it back, but that between the piers it was bowed outward. This, in connection with other evidence, seemed to point indisputably to a movement of the entire mass of the adjacent material toward the river, occasioned by the weight of filled material and buildings, and it seemed probable that this movement was shared by the silt to a considerable depth below the filling.

The first method that naturally comes to mind for providing a better foundation than can be done by simply spreading the bearings on the earth at customary depths is that of driving piles, and where there is reasonable certainty that these will always remain wholly submerged, this is generally the best possible foundation, considering its cost, for buildings of considerable but not of the greatest weight. The New York building law permits a load of 20 tons per pile, and engineers will consider this, when fair-size piles are used, to be within good practice; but there are many cases where it is certainly a great mistake to take the aggregate bearing capacity of a pile foundation to be the sum of the safe loads on the individual piles composing it. The sustaining power of a single pile may be said to be practically the sum of the friction which holds it on the sides, and the resistance to penetration at its lower end. It is obvious that in very many cases where a large number of piles are driven close to one another, the piles simply replace so much material which has been displaced to make room for them. It is true that the material remaining about them may by the process of driving become so much more compact that it increases the friction and perhaps the resistance to penetration at the lower ends of the piles; but if the stratum below the piles be at all yielding it is probably true that the bearing capacity of the foundation is the bearing capacity of the stratum below the piles plus the friction of what might be considered the outer side surfaces of the entire mass penetrated by the piles. In other words, the piles merely

replace so much yielding material and transfer the load to the stratum beneath them.

A practical difficulty which is apt to hamper the building of a good pile foundation for a building very seriously where there are a great number of piles close together is that, after driving the first few, the material near them becomes so compact that it is exceedingly difficult and sometimes impracticable to get the remaining piles down to anything like the contemplated depth. It may be comparatively easy to drive the first one, say 30 ft., and may become exceedingly difficult to drive those put down later to a depth of more than 10 or 15 ft. This difficulty is readily overcome where the use of the jet may be resorted to. This is often dangerous in proximity to other buildings, and, too, it sometimes seriously cracks the adjoining building to drive piles close to it.

With regard to the piles remaining permanently submerged, there have been some rather startling experiences in New York City. There is one building, the value of which is probably in the neighborhood of $1 000 000, built upon piles, the upper ends of which it was found before the completion of the building would be shortly exposed, and it is said that it was decided to enclose the entire foundation in a dam, so to speak, in which the water is kept by pumping at a safe height to cover the piles. One of the leading builders in New York a short time ago removed a building which rested on piles driven but a dozen years ago, and he found them seriously decayed. Throughout the gravel and sand deposits of the lower part of New York there is an abundance of fresh water, which rises and falls to a greater or less extent with the pressure of tide water upon it. The supply from springs must be very great, because there are a vast number of driven wells throughout the region, supplying water for steam and other purposes. The water level at any one point may be materially lowered at any time by pumping from a driven well in the vicinity or from the constant drainage of some leaking basement or other excavation. Thus it would seem that the permanence of any given water level in the city can rarely be relied upon.

In considering the provision of an adequate foundation for a building, the weight of which seems to require something better than the old style of simple foundations, the first natural thought is to increase in some way the spread of the foundation so that the unit weight on the material may be kept within allowable limits. In Chicago, where

the material on which the city is built consists generally of a thickness of 40 to 100 ft. of blue clay of more or less yielding character which can scarcely be loaded safely 2 tons per square foot, the general practice has come to be that of proportioning the area of the column foundations in a uniform ratio to the column loads upon them, in order to get equal settlement under all the columns. This has resulted in the so-called raft system of foundations, in which, by alternate layers of steel beams of lessening length, it is practicable to spread the bearing to a sufficient extent. This method requires the minimum depth of excavation and gives the minimum amount of cellar space. Short of some method of carrying the bearings to a lower and more substantial stratum, as by piles or by excavation to bed-rock, this would seem to be the best possible treatment of the problem under such conditions as exist at Chicago. That this method should be at all satisfactory requires a comparatively uniform condition of material under the entire building, uniform in character, in compressibility, in softness and in depth.

This raft method has been employed in some cases in New York. For buildings in the lower part of the city it is open to the objection that the conditions under the entire building are not apt to be uniform, and there is often the very serious objection that at some part, if not under the entire building, the material at some depth may be sandy, or of the nature of quicksand, and may yield or be relieved at some future time. Of course, there is always the question as to the durability of steel beams, even though encased in concrete, where they are below the water level.

In considering the loads to be provided for by the foundations for the Manhattan Life Building it was found that if piles were driven over the entire space to be covered by the building, enough piles could not be driven on the lot to sustain the building and load the piles within the limit permitted by the building law. Thus, unless the simple method of spreading the foundations were considered satisfactory, which in this case was out of the question, there was no way but to carry the column loads from the bed-rock, which in this case was 54 ft. below the Broadway street level. The borings taken on the lot indicated the existence of more or less quicksand, and it was feared that any effort to excavate for foundations in the open to the bed-rock would result in an inflow of material that would endanger the adjoining build-

ings. For this and other reasons, the architects, Messrs. Kimball and Thompson, decided upon the use of steel caissons sunk by the pneumatic process, and thus came about the first use of this method.

Its advantages are: First, the excavation can be carried on under pressure, which holds back from inflow any outside material; second, any obstructions met with in the sinking can be removed without serious difficulty or delay; third, the bottom can be examined, and, where necessary, leveled or stepped; fourth, the work can be executed with speed, because the caissons can be brought on the lot, finished or ready to put together, and while these are being sunk the brickwork to form the permanent pier can be built upon them, so that when the excavation for each foundation is completed, the pier itself is finished. This method has been employed in obtaining foundations for the American Surety Building and for the new Standard Oil Building, and its use is contemplated in other buildings soon to be erected. It would not seem worth while to deal in detail with the construction and sinking of the caissons, because the general method is familiar through its application to bridge foundations. Some points, however, should be mentioned. In these comparatively small caissons with vertical sides, sunk the entire distance through earth, the friction is in much greater proportion than occurs in bridgework. As soon as the brickwork, built as high as is practicable, proves of insufficient weight to make the caisson follow the excavation against the upward pressure of the air and the friction, it becomes necessary to put on a temporary load. This is done by piling on pigs of iron. Another respect in which this work differs from bridgework is the fact that excavations in the material should preferably be carried on by means of a Moran or other lock without permitting reduction of the air pressure.

Of course when the depth to hard bottom is not great and there is no running material over it, the excavation may be made in the open air under the protection of sheet piling, and this is in such cases the simplest and cheapest means of doing the work.

The foundations for the new Johnston building have been successfully put in by means of open wrought-iron cylinders sunk by the water-jet process. This method, while somewhat cheaper than the pneumatic, would seem to be open to the objection that it might not permit in some cases a proper examination and preparation of the bottom and of building the foundation in the dry, and, too, should flowing material under

heavy pressure from beneath an adjacent building be encountered, a possibly dangerous vent might be afforded. As yet the pneumatic process is the one safe and sure method for deep excavations, by which all dangers of quicksand or other difficulties can, with certainty, be quickly overcome and a perfect foundation constructed, and this, too, at a cost, where the conditions are determined, which can generally be estimated with comparative certainty.

While the necessity of better practice than has heretofore obtained in building foundations for heavy buildings is happily becoming somewhat more apparent, it is hard to understand the general lack of solicitude on this point on the part of those constructing new buildings. They are generally content to let the judgment of their architect govern, who probably has never before had such a problem to solve. Having engaged him they fail to see the necessity of employing in addition an engineer expert in foundations, and yet the writer ventures to say that in most cases, aside from the other advantages, his fee would be more than saved by the economy resulting from his guidance. It is probable that a sum not exceeding 3 or 4% of the cost of the entire building, added to what the cheapest possible shallow foundation would cost for one of the very high buildings, would cover the extra cost of carrying its foundations to the solid rock, when this is within 70 or 80 ft. of the surface. In many cases this extra cost would be more than offset by the value of the additional story or stories that could be provided beneath the surface.

When an owner has once realized the importance of getting his foundations on the rock he generally approaches the business treatment of the matter in a very narrow-minded and stupid manner. With a distrust born of the imposition of conscienceless contractors, he wants to be certain that his foundations will be completed for a given fixed sum, and this in advance of the determination of the various depths, corrected weights, dimensions and so forth, which is obviously impossible without injustice either to him or his contractor. The proper way for this work to be done is for the owner to engage a party whose integrity and capacity he can trust to do the work for him, for its net actual cost plus a fee as compensation or profit. Such an arrangement brings all interests into unison, permits much preparatory work to be done before the work could be let by contract, and gives the work finally to the owner at what, and only what, should be paid for

it. It results in the best work carried out in the quickest time, with freedom to improve plans as the work progresses, and with the pleasantest relations of owner, architect and foundation builder.

The author wishes to apologize for the absence of detail in this paper; it was intended to present only general considerations. The time would seem ripe for discussion of the matter of foundations of buildings. It should be brought to the minds of architects and property-owners that soils, like metals and woods, have limits of strength and cannot be overloaded without inviting trouble. If there is an absence of that principle to do things well, which should be an instinct with everyone who builds, they must be shown the false economy of their inadequate methods.

This general consideration of the subject treated has been offered in the hope that it will call forth valuable discussion, and that its author is not mistaken in assuming the Society to be the center from which such good influences as are needed must emanate.

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ERRATA

LIST OF MEMBERS.

FEBRUARY 10TH, 1896.

OFFICERS.

Page 27. BERNARD R. GREEN instead of BERNARD M. GREEN.

MEMBERS.

" 33. BASSEL, ROBERT
Royal Govt. Council of Construction, Weender Chaussée 13, Göttingen, Germany............... May 2, 1888

" 35. BOTH, CARL CHRISTIAN ADOLPH
U. S. Asst. Eng., U. S. Engr.'s Office, Portland, Me. Sept. 2, 1891

" 53. HAWKS, JAMES DUDLEY
Vice Pres. and Gen. Man. Detroit and Mackinac Ry., Detroit, Mich.......................... Dec. 3, 1884

" 69. OTAGAWA, MASAYUKI
Mech. Eng., Ashio Copper Mines, Shimotsuke, Japan.......... .... Jan. 2, 1895

" 74. RICKETTS, PALMER CHAMBERLAIN
Director of, and Prof. of, Mechanics, Rensselaer Pol. Inst., 17 1st St., Troy, N. Y... { Assoc. Feb. 4, 1886; M. Oct. 5, 1887 }

" 172. HAWKS, JAMES DUDLEY......M. 53
" 183. WILEMAN, ERASMUS D. Assoc. M. 100

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Vol. XXII. APRIL, 1896. No. 4.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publication.

CONTENTS.

SOCIETY AFFAIRS.

PAPERS.

ILLUSTRATIONS.

The price of publications is as follows: Proceedings, $6 per annum; Transactions, $10 per annum. Postage will be added when they are sent to foreign countries.

American Society of Civil Engineers.

OFFICERS FOR 1896.

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Vice-Presidents.

Term expires January, 1897:	*Term expires January*, 1898:
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BENJAMIN M. HARROD,	P. ALEXANDER PETERSON.

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Treasurer, JOHN THOMSON.

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Term expires January, 1897:	*Term expires January*, 1898:	*Term expires January*, 1899:
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ON UNITS OF MEASUREMENT:—George M. Bond, William M. Black, R. E. McMath, George F. Swain.

The rooms of the Society are open from 9 to 17 o'clock each business day, except Saturday (when they are closed at 15 o'clock), and at other times on application to the Janitor.

HOUSE OF THE SOCIETY—127 EAST TWENTY-THIRD STREET, NEW YORK.

Vol. XXII. APRIL, 1896. No. 4.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS.

CONTENTS:

MINUTES OF MEETINGS.

OF THE SOCIETY.

April 1st, 1896.—The meeting was called to order at 20.15 o'clock, Past-President Mendes Cohen in the chair; Charles Warren Hunt, Secretary, and present, also, 71 Members and 9 visitors.

Minutes of the meetings of March 4th and 18th, 1896, were adopted as printed in *Proceedings* for February, 1896.

The Secretary announced that the Board of Direction, having considered the resolution referred to it by the Society at the meeting of March 4th, 1896,* presented the following form of resolution to the Society for action:

Resolved, That in the opinion of the American Society of Civil Engineers it is very desirable that the tests of the strength of timber which have been conducted for a number of years past by authority of the Department of Agriculture, and which are likely to prove of much value

* See *Proceedings*, Vol. XXII, p. 72.

to the engineering profession, and to all who are interested in the building trades, be printed and published for general information at as early a date as can consistently be done.

On motion duly seconded, the resolution was adopted.

A paper entitled "The Transverse Strength of Beams as a Direct Function of the Tensile and Crushing Stresses of Material," was presented by M. Lewinson, M. Am. Soc. C. E. Correspondence on the paper from Messrs. J. B. Johnson, A. Jay DuBois, H. S. Prichard and C. O. Brown was read by the Secretary, and the subject was discussed by Messrs. L. L. Buck, O. J. Marstrand, Henry B. Seaman, W. H. Breithaupt, H. Waller Brinckerhoff, Charles E. Emery, John F. O'Rourke, F. W. Skinner, George R. Hardy, G. B. Waite, H. F. Dunham and M. Lewinson.

Ballots were canvassed, and the following candidates were declared elected.

As Members.

Frederick William Abbot, St. Louis, Mo.
George Adgate, Sioux City, Iowa.
George McClellan Derby, New Orleans, La.
Walter Leslie Fisk, Portland, Ore.
William Dean Janney, Ceredo, W. Va.
Eugene Ashbel Landon, Groton, N. Y.
Dickinson MacAllister, Chicago, Ill.
John Egbert McCurdy, Chihuahua, Mexico.
Henry Earle Riggs, Toledo, Ohio.
Alpheus Timothy Sabin, Louisville, Ky.
Charles Russell Suter, San Francisco, Cal.
Louis Lincoln Tribus, New York City.
William John Wilgus, Watertown, N. Y.

As Associate Members.

Percy Allan, Sydney, New South Wales.
Elisha Brown Baker, Indianapolis, Ind.
John Pascal Brooks, Bethlehem, Pa.
Edwin John Fort, Brooklyn, N. Y.
James Cowan Meem, Brooklyn, N. Y.
Walter Camp Parmley, Peoria, Ill.
Edson Mason Scofield, Hazelton, Ohio.
Alexander Stevens, Hoboken, N. J.
Sanford Eleazer Thompson, Newton Highlands, Mass.
Fred Elmer Wilcox, New York City.

The Secretary announced the election by the Board of Direction on March 31st, 1896, of the following candidates:

As Associate.

Theodore Ely Knowlton, Buffalo, N. Y.

As Juniors.

Thane Ross Brown, North Milwaukee, Wis.
Walter Bruce Gormly, Trenton, N. J.
George Albert Noska, New York City.
John Turner Smith, Austin, Tex.
William Dunham Vanderbilt, Brooklyn, N. Y.

The Secretary announced the deaths of the following members:

William A. Allen, elected Member May 6th, 1891; died March 21st, 1896.

Francis R. Fava, elected Member November 5th, 1890; died March 27th, 1896.

The Secretary also announced the death on March 26th, 1896, of George H. Nettleton, President and General Manager of the Kansas City, Fort Scott and Memphis Railroad. Mr. Nettleton was a subscriber to the Building Fund and the New Society House Fund.

Adjourned.

Wednesday, April 15th, 1896.—The meeting was called to order at 20.15 o'clock, President Thomas Curtis Clarke in the chair; Charles Warren Hunt, Secretary, and present, also, 124 members and 30 guests.

A paper entitled "Concerning Foundations for Heavy Buildings in New York City," by Charles Sooysmith, M. Am. Soc. C. E., was read by title, and correspondence on the subject from Messrs. R. L. Harris, George Hill, F. Collingwood, T. Kennard Thomson and Foster Crowell was read by the Secretary. The paper was discussed orally by Messrs. E. B. Gosling, P. C. Hains, W. A. Aycrigg, E. G. Freeman, E. Sherman Gould, Theodore Cooper, H. Waller Brinckerhoff, H. S. Prichard, W. G. Berg, Charles Macdonald, George B. Post and C. T. Purdy.

The President announced that the Annual Convention would be held in San Francisco, Cal., on or about June 30th, 1896.

The Secretary announced the election by the Board of Direction on March 23d, 1896, of William Price Craighill, Past President Am. Soc. C. E., Chief of Engineers, U. S. A., as Honorary Member.

The Secretary announced the death of Waterman Stone, elected Associate December 1st, 1886; died March 30th, 1896.

The Secretary stated that the discussion on the paper by M. Lewinson, M. Am. Soc. C. E., presented April 1st, would close on May 15th, 1896, and that the discussion on Mr. Sooysmith's paper would close June 1st, 1896.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

March 31st, 1896.—Eight Members present.

The question of the time and place for holding the next Annual Convention was considered, and the following committee was appointed, with power to select the place for holding the next Annual Convention and to make all the necessary arrangements therefor: Joseph M. Knap, Chairman; George A. Just, William Barclay Parsons, Horace See, Charles Warren Hunt.

Action was taken in regard to the matter referred to the Board by the Society at its last meeting concerning the appropriation of funds for investigations and tests of American timber.*

Applications were considered and other routine business transacted. One candidate was elected as an Associate and five as Juniors.

Adjourned.

ANNOUNCEMENTS.

MEETINGS.

Wednesday, May 6th, 1896, at 20 o'clock, a regular meeting of the Society will be held, at which a paper by Arthur L. Adams, M. Am. Soc. C. E., on "The Astoria City Water-Works," will be presented. The paper is published in this number of *Proceedings*.

Wednesday, May 20th, 1896, at 20 o'clock, a regular meeting of the Society will be held. The paper to be presented is by Theodore Cooper, M. Am. Soc. C. E., and is entitled "Some General Notes on Ocean Waves and Wave Force." It is printed in this number of *Proceedings*.

Correspondence on the above papers is invited from those who cannot be present at the meetings, and may be sent by mail to the Secretary. The papers with discussion will be published in *Transactions*.

DISCUSSIONS.

Discussion on the paper by M. Lewinson, M. Am. Soc. C. E., entitled "The Transverse Strength of Beams as a Direct Function of the Tensile and Crushing Stresses of Material," which was printed in *Proceedings* for March, 1896, will close May 15th, 1896.

Discussion on the paper by Charles Sooysmith, M. Am. Soc. C. E., entitled "Concerning Foundations for Heavy Buildings in New York City," which was printed in the same number of *Proceedings*, will close June 1st, 1896.

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* See *Proceedings*, page 81.

NEW SOCIETY HOUSE FUND.

The following subscriptions to the New Society House Fund have been received in addition to those published in *Proceedings* for January and February, 1896 :

H. D. Bush	$25	W. L. Cowles	$10
E. S. Dorr	10	S. C. Weiskopf	35
E. Del Monte	10		

The total amount subscribed up to April 13th, 1896, is $17 480, of which sum $13 905 has already been paid.

MEMOIRS OF DECEASED MEMBERS.

JAMES CLARENCE POST, M. Am. Soc. C. E.

Major, Corps of Engineers, U. S. Army.

Died January 6th, 1896.

James Clarence Post was born at Newburgh, N. Y., July 30th, 1844. In 1861 he entered the Military Academy at West Point, and on graduating four years later was appointed Second Lieutenant in the Artillery. He was soon promoted to First Lieutenant and transferred to the Corps of Engineers, with which he was afterward connected until his death. After acting for a short time as Assistant Engineer in the improvement of Government works in New England, he was appointed Assistant Professor of Mathematics at the Military Academy at West Point, where he remained for four years. The next three years were spent with the engineer battalion at Willet's Point, N. Y. From June, 1874, to November, 1882, he was Assistant Engineer under Lieutenant-Colonel Gillmore, and in temporary charge of his works to April, 1883. The next four years were spent in charge of river improvements in several states.

In May, 1887, Major Post was transferred to Washington as assistant to the Chief of Engineers, and in July, 1889, he became Military Attaché to the United States Legation at London. In July, 1891, he was a delegate to the Geographical Congress at Berne, Switzerland, and in 1893 attended the International Maritime Congress held in London.

From February, 1894, to December, 1895, Major Post was in charge of important works in the Northwest. The large jetty at the mouth of

the Columbia River was completed under his supervision, and his work in 1894, during a great flood in that river, when the Cascades Canal was in danger of serious injury, was highly commended by an examining board composed of General William P. Craighill, Past-President Am. Soc. C. E.; Colonel George H. Mendell, M. Am. Soc. C. E., and Major Marshall. During this time he was also in charge of the construction and equipment of a boat railway from the foot of the Dallas Rapids to the head of Celilo Falls, and of many river and harbor works. In addition to these duties he was engineer of the Thirteenth Lighthouse district, served as a member of boards on bridge construction and river and harbor improvements, and was in supervisory charge of the construction of bridges across various streams.

In December, 1896, he was relieved from duty at Portland and detailed as the successor of the late Orlando M. Poe, M. Am. Soc. C. E., at Detroit, and was about to assume his new duties, when he died.

Major Post was promoted to Captain in October, 1871 and to Major in September, 1886. He was married at London in 1892, and leaves a widow and infant son.

He became a Member of the American Society of Civil Engineers on February 6th, 1878.

SAMUEL HENRY SHREVE, M. Am. Soc. C. E.

DIED NOVEMBER 27TH, 1884.

Samuel Henry Shreve was born at Trenton, N. J., August 2d, 1829, his ancestors being among the colonial proprietors of New Jersey. He graduated from Princeton in 1848, and from the Harvard Law School two years later. He practiced law at Green Bay, Wis., and subsequently at Chicago until about 1853, when he returned East to prepare himself for the engineering profession, toward which he was attracted by a love of mathematics. His best work was done as an engineer and his reputation achieved as such.

He was engaged early in his career as an engineer in defining the complicated boundary lines under old colonial deeds in Ocean County. N. J., and made careful surveys for the purpose. Between 1860 and 1863 he was engaged as engineer on the Southern Railroad of New Jersey and its branches, and was connected later with other surface railways. He was interested in the elevated railway projects in New York City from their inception in 1866, but took no active part until he aided the development of the Gilbert Elevated Railway just before

it became the Metropolitan Elevated Railroad. He was retained as consulting engineer by one of the first rapid transit commissions in New York, and afterward by the Metropolitan Elevated Railroad. He became identified with the design and construction of the Sixth Avenue line and the structures on the east and west side of the city, built for the joint use of the New York and the Metropolitan Elevated Railways. At this time, the most active in elevated railway construction, Mr. Shreve was recognized as a leader in this class of engineering work, and in 1881 was appointed chief engineer of the Brooklyn Elevated Railroad, a position he held to the time of his death, November 27th, 1884. All the essential features of the first Brooklyn elevated road were designed by him, and the most important portion of the line had been completed before he died.

In 1873 he published a work on the strength of bridges and roofs, which was translated into French. It was one of the first to succeed the pioneer work of Squire Whipple, printed in 1847, and discussed only the simple forms of trusses. It was to have been followed by another volume on the cantilever and the more complicated trusses, which was partly written at the time of his death.

The mathematical attainments of Mr. Shreve were notable, but in his published writings he has made use of only algebraic processes. In order to avoid the use of the calculus in problems where the maximum or minimum values of a function have to be determined, the equation containing only the first and second powers of the independent variable, he devised a process which he explained in an article in *Van Nostrand's Engineering Magazine*, Vol. XV, page 530. While recognizing the utility and convenience of graphics, he preferred algebraic methods of computation, in which he became so expert, that, having written an equation of the second degree, he effected the transformations mentally, and wrote down the values of the variable after a brief pause. He served as Associate Editor of the 1878 edition of "Johnson's Encyclopedia."

Mr. Shreve became a Member of the American Society of Civil Engineers, May 19th, 1869. In Volumes III and IV of *Transactions* will be found two discussions of some length written by him on the subject of arch trusses.

LIST OF MEMBERS.

ADDITIONS.

HONORARY MEMBER.

			Date of Membership.
CRAIGHILL, WILLIAM PRICE	Chf. of Engrs., Brig.-Gen., U. S. A., War Dept., Washington, D. C.	M. Hon. M.	Oct. 7, 1885 March 23, 1896

MEMBERS.

ABBOT, FREDERICK WILLIAM	620 Chestnut St., St. Louis, Mo.	Assoc. M. M.	Oct. 7, 1891 April 1, 1896
LANDON, EUGENE ASHBEL	Groton, N. Y.		April 1, 1896
MACALLISTER, DICKINSON	260 Franklin St., Chicago, Ill.		April 1, 1896
MORLEY, FRED	Purdue Univ., Lafayette, Ind.	Assoc. M. M.	May 6, 1891 March 4, 1896
RIGGS, HENRY EARLE	424 The Nasby, Toledo, Ohio	Assoc. M. M.	Oct. 4, 1893 April 1, 1896
TRIBUS, LOUIS LINCOLN	84 Warren St., New York City	J. Assoc. M. M.	April 4, 1888 June 1, 1892 April 1, 1896
WILGUS, JOHN WILLIAM	Watertown, N. Y.		April 1, 1896

ASSOCIATE MEMBERS.

ADAMS, EDWIN GRIGGS, Jr.	Steelton, Pa.	Jan. 1, 1896
BROOKS, JOHN PASCAL	201 W. Broad St., Bethlehem, Pa.	April 1, 1896
CORTI, JOSEPH JAMES	Rivadaria 462, San Juan, Argentine Republic	Jan. 1, 1896
GRAYDON, AQUILLA ORMSBY	City Engr., London, Ont., Canada	Jan. 1, 1896
MEEM, JAMES COWAN	167 State St., Brooklyn, N. Y.	April 1, 1896
PARMLEY, WALTER CAMP	Room 10, Arcade Bldg., Peoria, Ill.	April 1, 1896
SCOFIELD, EDSON MASON	Box 7, Sub-Station 1, Youngstown, Ohio	April 1, 1896
STEVENS, ALEXANDER	1 Newark St., Hoboken, N. J.	April 1, 1896
THOMPSON, SANFORD ELEAZER	Newton Highlands, Mass.	April 1, 1896
WILCOX, FRED ELMER	Gerlach Hotel, New York City	April 1, 1896

JUNIORS.

Cummings, Noah	Chaseville, N. Y	March 3, 1896
Gormly, Walter Bruce	232 E. State St., Trenton, N. J	Mar. 31, 1896
Green, Francis Cushing	277 Pearl St., New York City	Feb. 4, 1896
Noska, George Albert	33 E. 17th St., New York City	Mar. 31, 1896
Vanderbilt, William Dunham	39 Monroe Pl., Brooklyn, N. Y	Mar. 31, 1896

CHANGES AND CORRECTIONS.

MEMBERS.

Appleton, Thomas	1653 Monadnock Bldg., Chicago, Ill.
Ballard, Robert	Menzies, West Australia.
Bogue, V. G.	1653 Monadnock Bldg., Chicago, Ill.
Del Monte, Emilio	142 W. 96th St., New York City.
Duane, James	878 East 166th St., New York City.
Fitch, Asa B.	Lessee Graphic Mines & Smelting Works, Magdalena, N. Mex.
Fuertes, J. H.	Camden, Ark.
Gay, Martin	1991 Lexington Ave., New York City.
Gemmell, R. C.	Room 509, Dooly Bldg., Salt Lake City, Utah.
Goldmark, Henry	1653 Monadnock Bldg., Chicago, Ill.
Grimshaw, J. W.	Australian Club, Macquarie St., Sydney, N. S. W.
Hegeman, W. W.	Spuyten Duyvil, New York City.
Keith, H. C.	Asst. Bridge Eng., N. Y., N. H. & H. R. R., New Haven, Conn.
Latrobe, C. H.	Merchants' Nat. Bank Bldg., Baltimore, Md.
Loree, L. F.	1003 Penn Ave., Pittsburg, Pa.
Masten, C. S.	Compania del Ferrocarril del Golfo, Rio Grande y Pacifico, Juarez, Mex.
Olney, G. R.	28 Cortland St., Middletown, N. Y.
Opdyke, S. B.	1222 Belmont Ave., Station B, Philadelphia, Pa.
Orange, James	Leigh & Orange, Hong Kong, China.
Paret, M. P.	Lake Charles, La.
Sears, Alfred F.	1082 Front St., Portland, Ore.
Van Buren, Robert	58 West Ave., Norwalk, Conn.

ASSOCIATE MEMBERS.

Bauer, J. L.	68 Bible House, New York City.
Bryan, Kennerley	Erie Co. Bank Bldg., Buffalo, N. Y.
Cockroft, C. A.	19 Ackerman Bldg., Binghamton, N. Y.
Hazard, Erskine	P. O. Box 1906, Johannesburg, South African Republic.

Lund, G. A. ....106 W. 61st St., New York City.
McKenzie, Thomas ....Box 118, Rockville, Conn.

JUNIORS.

Baehr, W. A. ....57 32d St., Milwaukee, Wis.
Berrall, James.................373 Bloomfield Ave., Montclair, N. J.
Lorini, M. ....88 Highland Ave., Yonkers, N. Y.
Michie, W. R ....Asst. Eng. P. R. R., Greensburgh, Pa.
Pegram, W. M ....115 E. 35th St., New York City.
Seltzer, H. K ....Care Engr.'s Office, K. C., P. & G. Ry., Kansas City, Mo.
Taintor, W. M. ....Care Div. Eng., State Canals, Syracuse, N. Y.
Williams, S. W ....Care Passaic Rolling Mill Co., Paterson, N. J.

DEATHS.

Allen, William A. ....Elected Member May 6th, 1891; died March 21st, 1896.
Fava, Francis R. ....Elected Member Nov. 5th, 1890; died March 27th, 1896.
Nettleton, George H. ....Subscriber to Building Fund; died March 26th, 1896.
Stone, Waterman ....Elected Associate Dec. 1st, 1896; died March 30th, 1896.
Swift, McRee.......................Elected Fellow March 9th, 1870; died April 5th, 1896.

BOOK NOTICE.

THE WATER SUPPLY OF THE CITY OF NEW YORK, 1658-1895.

By Edward Wegmann, M. Am. Soc. C. E., author of "The Design and Construction of Masonry Dams." Cloth, 10 x 12 ins., pp. 316, with 148 plates and 73 figures in text. John Wiley & Sons, New York; Chapman & Hall, London, 1895.

Ever since the publication of Mr. Wegmann's former work, in 1888, he has been engaged in the preparation of the present volume, and has expended much time and labor in the search for necessary data, especially as regards the early history of the introduction of water into New York City. The oldest records have been examined and official documents studied in order to obtain information on the subject. E-pecial attention has also been given to full details of new works executed during late years.

The principal chapters take up the early works and projects, the construction of the old Croton Aqueduct, the maintenance and extension of the water supply by the Croton Aqueduct Department and the Department of Public Works, the construction of the New Croton Aqueduct with the engineering details of the work, and the features of the Croton watershed. Comprehensive engineering details of the New Croton Aqueduct, the formulas used in estimating the flow of water, and the results obtained after completion, are given in the chapter on the construction of the aqueduct.

The appendix shows the form of contract of the Aqueduct Commission, contract prices, water rates, specifications for construction of pipe lines, dams, gate-houses and engines, boilers, etc., necessary to the work, rules and regulations of the Board of Health, flowing capacity of the aqueduct, rainfall in the Croton Basin, and other valuable data.

A large number of plates, both new and reproduced from the reports of the Aqueduct Commission, illustrate the construction of the dams and gate-houses, the accessory machinery, contractors' plant, and other allied subjects, and tables of cost are given by which an engineer is able in most cases to secure readily all the data relating to any part of this important system of water-works. Among the illustrations are numerous half-tones of interesting work completed and in progress, and there are many cuts printed with the text in addition to the collection of folding plates.

ADDITIONS TO

LIBRARY AND MUSEUM.

From Horace Andrews, Albany, N. Y.:
Annual Report of the City Engineer of Albany, N. Y., for the year ending January 1st, 1896.

From G. C. Baravelli, Rome, Italy:
Nota su alcuni Aiuti alla Esecuzione dei Calcoli Numerici.

From Board of Railroad Commissioners, Boston, Mass.:
Twenty-seventh Annual Report, January, 1896.

From Board of Trustees of the Sanitary District of Chicago:
Proceedings, January 8th to March 11th, 1896.

From Boston Public Library, Boston, Mass.:
Bulletin for January, 1896.

From George Bowers, Lowell, Mass:
Twenty-third Annual Report of the Lowell Water Board for 1895.

From Bronx Valley Sewer Commission, New York:
Report to the Legislature of New York, March 6th, 1896.

From Canadian Institute, Toronto, Canada:
Transactions No. 8, December, 1895.
Archæological Report, 1894–95.

From F. W. Cappelen, Minneapolis, Minn.:
Annual Report of the City Engineer of the City of Minneapolis for the year ending December 31st, 1895.

From O. M. Carter, Savannah, Ga.:
The Influence of Sea Water on Hydraulic Mortars.

From Central Fire-Proofing Company, N. Y.:
The Fire-Proofing of Buildings and the Improvements in Architectural Methods.

From J. M. Clark, Toronto, Canada:
The Functions of a Great University.

From Charles Corner, Austin, Tex.:
Second Annual Report of the Railroad Commission of the State of Texas, for the year 1893.

From W. P. Craighill, Washington, D. C.:
Annual Reports of the Mississippi River Commission for the years 1890, 1891, 1892 and 1895.

From W. Bell Dawson, Ottawa, Canada:
Survey of Tides and Currents in Canadian Waters, Report of Progress.

From Mordecai T. Endicott, Washington, D. C.:
Report of the Board of Engineers for the purpose of ascertaining the feasibility, permanence and cost of construction and completion of the Nicaragua Canal by the route contemplated and provided for by the act which passed the Senate January 28th, 1895. Doc. No. 279, H. R., 54th Congress.

From Engineer Commissioner, District of Columbia, Washington, D. C.:
Report of the Operations of the Engineer Department of the District of Columbia for the year ending June 30th, 1895.

From Engineers' Club, New York:
Constitution, Rules, Officers and Members, 1896.

From John F. Fairchild, New York:
Report of the Bronx Valley Sewer Commission.

From Desmond FitzGerald, Brookline, Mass.:
Report on the proposed Extension of Water-Works Tunnel, Intercepting Sewerage System and River Flushing Tunnel for Cleveland, Ohio.

From Bradford L. Gilbert, New York:
Sketch Portfolio of Railroad Stations and Kindred Structures.

From Clemens Herschel, New York:
Experiences sur la Contraction des Veines Liquides et sur la Distribution des Vitesses dans leur Intérieur, par M. Bazin.

From John W. Hill, Cincinnati, Ohio:
Report to the Honorable Board of Administration on the Extension and Betterment of the City Water Works, by the Engineer Commission, Cincinnati.
Water Supply for Cities.

From E. W. Howe, Boston, Mass:
Fourth Annual Report of the Board of Commissioners of the Department of Parks, Boston, Mass., for the year 1878.

From Institute of Marine Engineers, Stratford, Eng.:
Volume V of Transactions, Discussion on the "Sizing of Marine Engines."
Volume VI, "Raising Wrecks and Sunken Vessels."

From Massachusetts Institute of Technology, Boston, Mass.:
Annual Report of the President and Treasurer, December 11th, 1895.
Annual Catalogue, 1895-96.

From Midland Institute of Mining, Civil and Mechanical Engineers, Newcastle, England:
Proceedings of General Meeting, November 16th, 1895.

From Mississippi River Commission, St. Louis, Mo.
Reports and Tables relating to dredging operations and tests for capacity of dredge *Alpha*, 1894-95.

From New York Railroad Commissioners, Albany, N. Y.:
Twelfth Annual Report for the fiscal year ending June 30th, 1894.

From North of England Institute of Mining and Mechanical Engineers, Newcastle, England:
Transactions, Vol. XLIV, Part 5; XLV, Parts 1, 2 and 3, 1895-96.

From Patent Office, London:
Patents for Inventions, Abridgments of Specifications, Gas Manufacture, 1884-88; Umbrellas, Parasols, and Walking Sticks, 1884-88; Lace Making, Knitting, Netting, Braiding and Plaiting, 1884-88.

From M. E. Ransome, Cleveland, Ohio:
Report on the proposed Extension of Water-Works Tunnel, Intercepting Sewer System and River Flushing Tunnel for Cleveland, Ohio.

From Alfred F. Sears, Portland, Oregon:
Sanitary Care of Men in Masses.

From Clinton B. Sears, Duluth, Minn.:
Photograph of Marquette Breakwater showing effects of storm of January 23d, 24th, 1896.

From Collingwood Schreiber, Ottawa, Canada:
Annual Report of the Department of Railways and Canals (Dominion of Canada) for the fiscal year from 1st July, 1894, to 30th June, 1895.

From Hamilton Smith, London, Eng.:
Third Annual Statement of the Alaska-Mexican Gold Mining Company for the Year 1895.

From Society of Naval Architects and Marine Engineers, New York:
Transactions, Vol. III, for 1895.

From State Board of Agriculture, Denver, Colo.:
Seventeenth Annual Report for 1895.

From State Board of Health, Providence, R. I.:
Report of the Results obtained with Experimental Filters at the Pettaconset Pumping Station of the Providence Water Works

From Swedish Technological Society, Stockholm, Sweden:
Förteckning öfver Svenska Teknologföreningens Ledamöter, Februari, 1896 (List of Members).

From U. S. Department of the Interior:
Report on the Statistics of Agriculture in the United States at the Eleventh Census, 1890.
The Production of Cement in 1894.

From U. S. Navy Department:
Notes on the Year's Naval Progress, General Information Series, No. XIV, July, 1895.
Astronomical Papers prepared for the Use of the American Ephemeris and Nautical Almanac, Vol. VI, Part III, Tables of Venus.

From U. S. Treasury Department, Bureau of Statistics:
Statistical Abstract of the United States, 1895.

From U. S. Treasury Department, Light House Board:
Annual Report of the Light House Board for the fiscal Year ended June 30th, 1895.

From U. S. War Department, Chief of Engineers:
Fourteen Reports on the Improvement of certain Rivers and Harbors.

From University of the State of New York:
Extension Bulletins Nos. 9, 10, 11 and 12, Summer Schools, Extension of University Teaching in England and America, Study Clubs and Report of Extension Department, 1894.

From Edward Wegmann, Katonah, N. Y.:
The Water Supply of the City of New York, 1658-1895.

1896. APRIL, No. 4.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

PAPERS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

THE ASTORIA CITY WATER-WORKS.

By ARTHUR L. ADAMS, M. Am. Soc. C. E.

TO BE PRESENTED MAY 6TH, 1896.

It is an attractive feature of the engineer's vocation that each engagement presents for solution new and often interesting problems which tax both skill and ingenuity, and it is seldom that the results, when carefully observed and properly recorded, are not of both interest and profit to others in the profession. The author proposes to make brief mention of the old water-works of Astoria, Ore., and to present a description of the works just completed, and to accompany it with such notes and observations incident to construction, cost and final determination of results as many engineers in charge of work record in their private note-books, but, at the expense of the profession at large, often fail to make a matter of public recital. In the amount of expenditure involved these works are in no way exceptional, but in variety of work and consequent interest, it is believed that they have not been often exceeded, even by works of considerably greater magnitude.

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

THE OLD WORKS.

The city of Astoria, first established in 1811 by John Jacob Astor, and made memorable by Washington Irving's "Astoria," is situated on the south shore of the Columbia River, here 7 miles in width, about 12 miles above its mouth, and occupies a much broken peninsula rising to a height of 600 ft. between the Columbia River and Young's Bay.

In 1883–84, the Columbia Water Company, a private corporation, built a system of works utilizing Bear Creek, a small mountain stream flowing into the Columbia about 7 miles above the town, as a source of supply. The water was conducted by gravity to the town through a line of lap-welded wrought-iron pipe of the following sizes and lengths: 1 825 ft. of 10-in., 2 275 ft. of 8-in., 59 000 ft. of 6-in. The line terminated in a reservoir of 500 000 galls. capacity built at a flow-line elevation above mean low tide of 166 ft., from which the water was distributed over the town through pipes ranging in size from 6 ins. to 1 in., the smaller sizes largely predominating. No provision was made for fire protection from these works. No especial interest attaches to them other than as showing a remarkable example of how works may be built by so-called practical men without incurring any expense for engineering supervision; 140 000 galls. in 24 hours is all that the pipe-line could ever be made to deliver into the reservoir, not over 60 or 70% of what might reasonably have been expected if properly built. The line was laid from the source immediately to tide water in the Columbia, without recourse to instrumental work, and thence down the tide flats to town, thus subjecting the entire line to the greatest pressure possible, and to the destructive action of the salt water, which in the course of a very few years so thoroughly honeycombed the pipe as to render it a very serious question from day to day whether or no water could be supplied to consumers on the morrow. In addition to this the pipe was laid without regard to either alignment or grade, and with so little cover that the lateral components of the thrust at sharp angles frequently pulled the joints entirely apart.

This train of evils consequent upon stupid work led in 1891 to an agitation on the part of the citizens which culminated in the appointment by an act of the State Legislature of a Board of Water Commissioners, authorized to purchase the works of the Columbia Water Company, to reconstruct the same, or to build new works with a view

to greater efficiency and supply, and to issue municipal bonds in an amount not exceeding $500 000 necessary for the accomplishment of these ends.

Shortly after its organization, the Commission purchased the old works for the sum of $75 000. Some effort was then made to secure an improvement of the service without resorting at once to entire reconstruction, but without any satisfactory results being attained, while repeated interruptions in the water supply by failure in the gravity line, the insufficiency of the supply, and the inability of the system as built to afford water to any of the higher elevations of the city, all rendered apparent the necessity for speedy construction of new works.

The New Works.

In November of 1893 the author reported for the Commission on an increased water supply, and recommended the construction of a new system substantially as has been subsequently carried out. During the following spring a beginning was made on the preliminary surveys and plans, but the general business depression of 1893 influenced the Commission to suspend operations indefinitely. In July, 1894, however, matters were again taken up with the intention of getting construction under way the following spring. In order to meet in a measure the pressing public demand for more water pending the construction of the new works, the old gravity line was parted at tide-water elevation, about 8 000 ft. distant from the reservoir, and diverted into a tank, thereby securing about 160 ft. more fall in the pipe line and an increase of one-half in the discharge. From the tank the water was pumped to the reservoir by arrangement with the electric street railway company to supply the power. The plans for the new works were completed and the programme for construction carried out as previously purposed.

Water Supply.—The water supply is derived from Bear Creek, the diversion being made about 1 mile farther up the stream than was selected in the construction of the old works. This is a beautiful mountain stream having a drainage area above the diverting point of 4.82 square miles, all of which is heavily timbered and covered with a dense growth of moss and ferns. During the rainy season the run-off varies from 10 000 000 to 30 000 000 galls. in 24 hours, and the dense vegetation serves to retain and prolong the supply during the few

weeks of dry weather in August and September to an extent very unusual in a stream having so limited a drainage area. The yield of this area was materially increased by diverting into Bear Creek above the head works another stream, Cedar Creek, which originally entered a mile farther down, this work being accomplished at almost no expense. Careful weir measurements of the flow of the stream during the lowest stages show the following results:

1890.........	5 118 000 galls. in 24 hours	below	mouth of	Cedar Creek.
1891.........	4 763 000 "	"	"	"
1892.........	4 280 000 "	"	"	"
1893.........	2 646 000 "	above	"	"
1894.........	2 400 000 "	"	"	"
1893.........	718 000 "	in Cedar Creek.		

From these results and because of the ease with which about 50 000 000 galls. can be stored just above the diverting weir, it was assumed that a daily supply of 4 000 000 galls. could be made available from this source with a reasonable degree of certainty. It was accordingly determined that this figure should be made the basis for all computations of capacity in the new works. The construction of the storage reservoir was, however, to be deferred until the demand for a supply in excess of that afforded by the stream direct should necessitate its construction. This determination as to capacity in the construction of the new works was also influenced by the rapid growth of the town, now having a population of fully 10 000, and by the fact that the large and available sources of supply for the future city will all be brought in over the same general route adopted for the new line.

General Arrangement.—Briefly outlined, the new works consist of the following structures: The head works on Bear Creek, a small masonry diverting weir with a crest elevation of 589.35 ft., diverts the water through a head gate into a small receiving basin, from which it is led through an 18-in. wood-stave pipe to a masonry settling basin 1 000 ft. distant, where it is screened and weired. The water is then conducted through pipes of the following character and order: 11 956 ft. of 18-in. wood-stave pipe, 1 239 ft. of 16-in. riveted steel pipe, 10 450 ft. of 18-in. wood pipe, 2 413 ft. of 16-in. steel pipe, 3 606 ft. of 18-in. wood pipe, 12 776 ft. of 16-in. steel pipe, and 13 082 ft. of 18-in.

wood pipe—in all a little over 10.5 miles, to an elevation within the city limits of 425.75 ft. Thence it passes by a rapid descent through 5 574 ft. of 14-in. steel riveted pipe to the power and gate house at the new reservoir. The elevation of the water surface of the reservoir when full is 282.4 ft., and of the point of power development 289.00 ft. The reservoir has a capacity of 6 250 000 galls. and is located on the Young's Bay side of the peninsula, while the city is situated principally on the Columbia side. From the reservoir the water is conveyed to the distributing system through an 18-in. pipe laid in a tunnel 1 200 ft. long, passing through the divide. The distribution is divided at present into a low and high service, the lower being supplied from the small reservoir previously connected with the old works, and the high service from the new reservoir. These two services, in case of fire, are thrown together, the lower reservoir cut out by the operation of a check valve, and the pressure secured from the upper reservoir. This end is accomplished by the operation of two hydraulic lift gates which are both opened and closed from the central fire station by means of a special hydraulic gate governor designed for this purpose. Two other surfaces of greater elevation will eventually be added, three of the four being supplied by gravity. The fourth will be supplied by pumping with water power at the new power house.

Construction.—It was expected that by letting all contracts for materials and construction during the winter months, that the contractors would be able to complete the work during the dry season, usually lasting in this locality from June 1st to October 1st. Accordingly advertisement was made in December, and bids opened on January 10th, 1895. Proposals were invited on the work divided into seven divisions, each being segregated into the different items entering into it, and a percentage of reduction from the aggregate amount of the proposal, asked in consideration of the entire seven divisions being awarded to the same person. The divisions referred to were as follows:

First.—Clearing and grubbing the conduit right of way and grading the road alongside it; making necessary bridges and culverts; constructing a telephone line; excavating and refilling the conduit trench, and excavating the reservoir.

Second.—Head works, diverting weir and settling basin.

Third.—Lining reservoir, erecting gate and power house, including the furnishing and placing of all gates, fittings and appliances in it.

Fourth.—Wooden stave conduit, furnishing and laying.

Fifth.—Riveted steel conduit, furnishing and laying.

Sixth.—Distributing system.

Seventh.—Tunnel.

Eighth.—All cement required on the work.

The almost entire absence of construction work on the Pacific Coast at this time rendered the bidding exceedingly spirited, with the final result that the Commission was confronted with the alternative of awarding several important divisions of the work on proposals, which, though formal in the last degree, and supported by contractors determined to have their rights recognized and to secure the work at any cost, were manifestly less in amount than that for which the work could be performed; or on the other hand, rejecting these bids and awarding to higher bidders. The author holds, in the much-discussed question to which this gives rise, that though a private person or company may often, with creditable discretion, discard a bid that is too low, yet in handling the funds of a municipality, if the proposal is strictly formal and the sureties satisfactory, the administrator of such funds cannot with due propriety and proper regard for the wishes of the public whom it serves discard such a bid. The subject has proved an interesting one in Astoria in the light of after developments. After a careful consideration of the matter, the awards were made to the lowest bidder in each case, and divisions 1, 2, 3, 6 and 7 were let in accordance with the above hypothesis, all but No. 6 being united in one award. Nos. 5, 6 and 8 were each awarded separately to different parties. While it was to be expected that some unpleasant conflict of interest would arise from this dividing of the work, yet the large saving to the city thereby was considered amply compensative.

Proposals were invited on $200 000 of bonds at the same time that bids were asked on the construction, but through certain unexpected difficulties in their negotiation, the money was not realized on them until the following May, when the contractors were immediately notified to proceed with the work. In the mean time the contracts for construction had been held in trust by a third party, to be delivered on the mutual consent of the principals.

The delay in getting the work started, and the necessity of ordering most of the steel used in the construction from the East at a time when the suddenly increased demand made it exceedingly difficult to get

orders from a distance filled, caused it to be very late in the summer before work was well started on several of the contracts.

Affairs moved along as smoothly as can be expected on work where the majority of the contractors are losing money, until the middle of September, when the contractor for divisions 1, 2, 3 and 7 suddenly failed, and disappeared to escape the vengeance of some hundreds of unpaid laborers. The customary suits, attachments and injunctions immediately followed. A few thousand dollars allowed on estimates, still in the hands of the Commission to the credit of the bankrupt concern, neither public funds nor public works being attachable in Oregon, were by the order of the court paid over to a receiver. The Italian element, which largely predominated among the laborers, not being satisfied with the slow process of law in the recovery of their claims, and being incited by irresponsible and incendiary agitators, after trying for some days to force the payment of their employers' private debts out of the public funds in the hands of the Water Commission by parading the streets in full force in martial order and by besieging the offices and residences of the members of the Commission and of the engineer, finally inaugurated a strike against the city. Arming themselves with guns, axes and clubs they forced the suspension of all work outside the immediate confines of the town, notified all parties that any attempt to resume, until they had been paid in full, would be at the peril of their lives, and that unless they were speedily settled with, the works already built would be destroyed with giant powder. The Commission resisted the revilings and ill-considered advice of a large but misguided portion of the citizens, and steadfastly refused to incur a single expenditure not legally authorized. In the mean time arrangements were made with the bondsmen of the defunct company to proceed with the work, and public sentiment was satisfied when all strikers were offered work, payment of wages to be made weekly, and guaranteed by the city. As was anticipated, the strikers, misinterpreting these actions, attributed them to fear instead of sympathy, and remained as obdurate as ever, refusing to change their position until all claims for back wages were satisfied. This being impossible, however desirable, through lack of suitable legislation in Oregon, and public sympathy being then largely withdrawn, a determined effort was made to start the work, which was without much difficulty effected by the moral suasion of 25 Winches-

ters. Most of the men returned to work in the course of a few days; but after trying in vain for two weeks to get decent and expeditious work from this element, which, through the influence of agitators and Italian lawyers, constantly maintained a menacing attitude, the author gave up in despair and had the entire force summarily removed from the work, and new laborers employed.

The gravity line was completed, and the water formally turned into the new reservoir on December 21st, in the presence of a large number of enthusiastic citizens. Although this was ostensibly the first water to enter any part of the new work, perhaps it is unnecessary to add that everything had been very quietly but thoroughly tested beforehand; and any imperfections in workmanship, liable to grow into a mountain of difficulty in the eyes of the populace, were well taken care of in advance.

The tunnel was completed on February 22d, and water was turned through from the reservoir into the low-service distribution about February 10th. In the meantime, however, the city had for some weeks been supplied from the new conduit by laying a temporary line of pipe up over the tunnel point and down to the low-service reservoir. The high service is not yet quite complete, as most of the pipe used in it was taken from the upper part of the old gravity line and from the old distribution, which could not be disturbed until the water supply was available from the new source and through the new distribution. The entire plant will be completed in less than one year, although the larger part of the work has been done during the rainy season, not a light matter where the average annual rainfall is in excess of 75 ins. The prosecution of the work as a whole was very trying to both contractors and engineers. To the former, because only one succeeded in completing his work without sustaining a loss, to the latter because of the extreme difficulty always experienced in enforcing the provisions of a contract under such conditions. By a combination of circumstances, fortunate to the city, the works have been built at a remarkably small cost; and the author doubts if there is another system on the Pacific Coast where similar results have been accomplished with a smaller expenditure.

During construction, daily reports of force, materials used, and progress made on each part of the work, were made to the Chief Engineer; and these have been made the basis of carefully prepared esti-

mates of cost, which are submitted in part with this paper. They may be considered entirely reliable. These reports, by the way, have proved invaluable in unraveling the affairs of the contracting company that failed, and in settling many claims regarding extras, etc.

Head Works.

The diverting weir is located near the head of a narrow, rocky and precipitous gorge on Bear Creek. It is very simple in character, is founded on solid rock, is entirely tight, and serves to divert the water through the head gate into a small receiving chamber, from which it enters the pipe leading to the settling basin, while the surplus water passes on over the weir. The masonry is of rough rubble basalt, quarried in the immediate vicinity, the face stones being squared. The mortar is made in the proportions of 2 to 1 of sand and imported Portland cement. The receiving chamber is covered with a frame and trap door securely bolted to the masonry.

The settling basin is located 1 000 ft. below the diverting weir. It consists of a masonry basin 50 ft. long by 8 ft. in width, having an average depth of 6 ft. The water enters at the end, flows the length of the basin, where, after passing through duplicate screens and over a measuring weir, it enters the pipe line, which continues uninterrupted to the city reservoir. The masonry is of the same general character as that of the diverting weir, and is finished on the inside with ½ in. of cement mortar, covered with two coats of asphaltum. The screens are of No. 12 sheet brass, perforated with ¼-in. holes, framed with two 1-in. angle irons, and rest in channel iron guides set in the masonry. They are handled by means of a block and tackle hung from a traveler. The measuring weir is of iron plate, has contractions and is provided with a weir gauge by which the gallons of water passing the weir in 24 hours are indicated on a graduated brass scale mounted on an iron pedestal. The index rises and falls with a copper float operating in a stand-pipe set in the wall of the basin, and communicating by means of a pipe with the water below the screens and above the weir. The entire settling basin is enclosed in a corrugated iron-covered structure. This basin reduces the velocity of flow to a rate that results in the precipitation of all heavy matter, and the screens stop all leaves, moss and fir needles with which the water is heavily charged during the rainy reason. Cleaning the screens, which

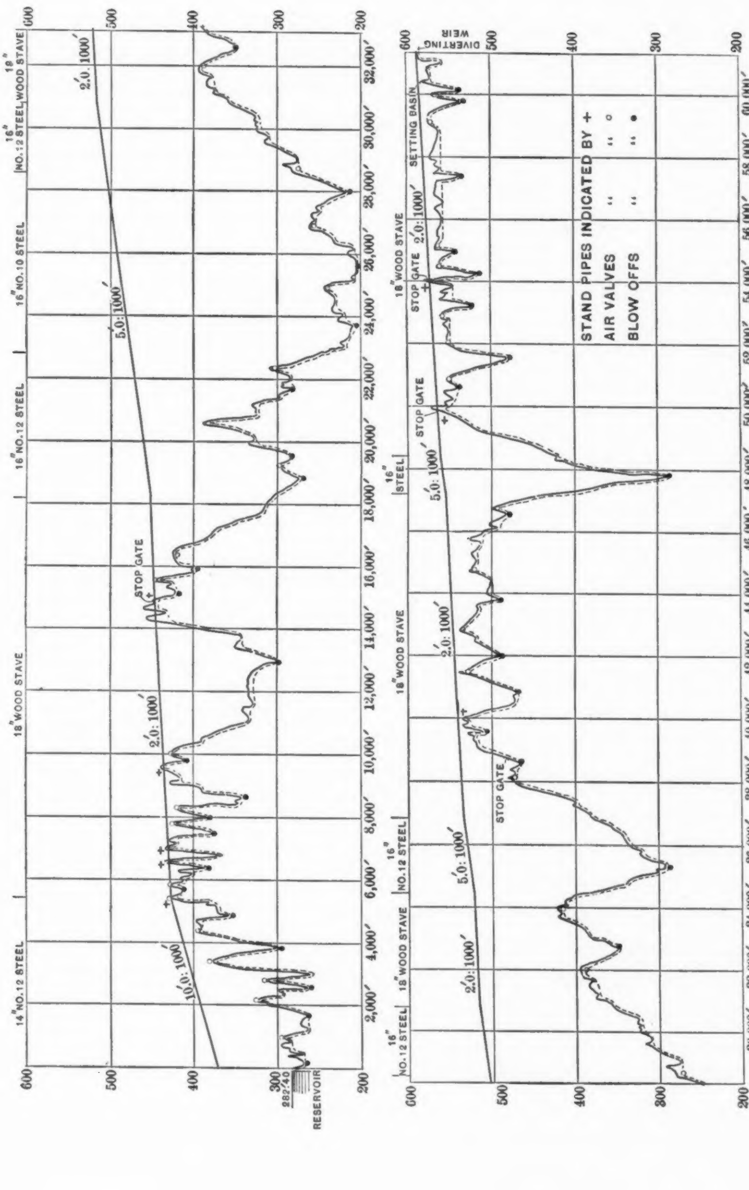
is usually accomplished with a piece of square rubber packing fastened to the edge of a wooden hoe, is necessary about twice a day during the wet season in order to maintain a full flow in the pipe line. Provision is made for flushing out the basin from the bottom, and for discharging the surplus waters through an overflow pipe when the screens become clogged, or a sudden rise occurs in the stream. The management of the work on the diverting weir and settling basin was, on the whole, so poor that a statement of the cost would have no especial value.

The Pipe Line.

Development.—The gravity line consists of approximately 7½ miles of 18-in. wood-stave pipe, 3 miles of 16-in. and 1 mile of 14-in. riveted steel pipe. The author was influenced to recommennd the use of these materials instead of cast iron by economic motives, involving the consideration of many points, beside the question of first cost; and the wood instead of steel for a variety of reasons, some of which are as follows:

Although there are many examples to the contrary, the author has seen steel riveted pipe of light gauge, designed with a reasonable factor of safety, go entirely to pieces in six years of service. With due regard for proper conditions, on the contrary, he has no doubt that the life of wood-stave pipe is much in excess of that of light gauge steel. Its carrying capacity is very much greater at the beginning, and far more likely to remain practically constant. Its transportation over rough roads is much easier, and the saving in first cost is very great. In this case the saving in first cost over a similar size of No. 12 steel was 43%, and nearly 50% over one of equivalent carrying capacity, 19.15 ins. in diameter. That this advantage, on a basis of equivalent carrying capacity, will be largely increased in the course of years can scarcely be doubted. The cost of any other material would in this case have left no choice with the city but to build a line of much less capacity. The use of the stave pipe will be seen later to have materially influenced the character and details of the location.

Location.—As high a line was located as possible, by following down the divide between the tributaries of the Columbia and Young's River, thus avoiding heavy pressures. The exceeding brokenness of the profile (see Fig. 1) gives some idea of the character of the country traversed, although curvature was very freely used in order to avoid sum-


STAND PIPES INDICATED BY +
AIR VALVES " " o
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RESERVOIR
STOP GATE
SETTING BASIN
DIVERTING WEIR
14" NO. 12 STEEL
18" WOOD STAVE
16" NO. 12 STEEL
16" NO. 10 STEEL
16" NO. 12 STEEL
18" WOOD STAVE
16" STEEL
10.0: 1000
5.0: 1000
2.0: 1000

FIG. 1.

mits and depressions, fully 35% of the line being on curves, either vertical or horizontal. The final line was staked from a paper location, laid on a map of preliminary survey having 5-ft. contours. This method was expensive, but unavoidable in securing a satisfactory line, since the entire distance is through forest, windfall and undergrowth of such density as only those familiar with the Pacific Northwest can form any conception of. Here an instrumentman may consider himself fortunate in finding a place where he can see 25 ft. ahead without clearing, and the stranger, supposing himself to be on fallen logs resting directly on the ground, is often surprised when a misstep sends him plunging down 10 or 15 ft. through ferns, brambles, and among rotten logs to the real ground beneath. Half a mile of line a day with a fully equipped party is excellent progress. The expense of such a method of location was well repaid by a saving of about 1 mile in distance over a very good preliminary. In this connection it may be interesting to note that though the country is so rough, the actual length of the completed pipe is but 0.6% longer than horizontal measurement. One of the most annoying features of the location was the difficulty experienced in securing the land connections with sufficient accuracy for the writing of deeds for rights of way, since much of the country traversed has been laid out into boom-city additions, with lots of 25-ft. frontage, the work having usually been done in the office, without much regard for even correct external boundaries, which were found in the field in almost every case to be entirely at variance with the recorded plats. Many of these additions had been peddled all over the country, entailing the greatest difficulty in securing a satisfactory adjustment of right-of-way matters. By reference to the profile, it will be seen that the location of the wood-stave

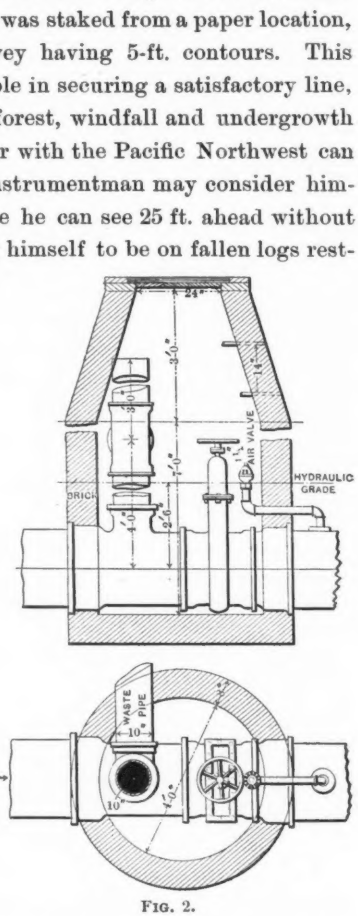

FIG. 2.

pipe is so made with reference to the hydraulic grade line that at intervals the two approach near enough to permit the use of open stand-pipes (Fig. 2) at these points, while the intervening sections are kept at a lower elevation, causing the pipe to be always full of water, regardless of the quantity flowing, thus realizing the chief essential to long life in stave pipe. At only one point has it been impossible to apply this method, and there the same end is attained by inserting an 18-in. stop gate. By partially closing this when the pipe is carrying less than a full supply, the hydraulic gradient is raised and the preceding summits filled. Danger of over-pressure on the pipe by reckless closing of the gate is entirely removed by the presence on a preceding summit of an open 6-in. stand-pipe. Three hundred feet is the minimum length of radius on horizontal curves, though 60 ft. is frequently employed for vertical curves on the stave pipe.

Pressures.—The maximum pressure adopted for the stave pipe was 150 ft., though this has been exceeded at one point for a few hundred feet, a pressure of 172 ft. being attained. This limit was decided on, not because the stave pipe cannot be made to withstand safely a somewhat greater pressure, but because the author did not wish to depart unnecessarily from conservative practice, and because this was estimated to be about the point of equilibrium in cost between the 18-in. wood and the 16-in. No. 12 steel pipe. The latter was used up to a pressure of 225 ft. head, and No. 10 steel for all in excess, reaching a maximum of 290 ft.

Broken Gradient.—In securing the delivery of the amount of water determined upon, about 4 000 000 galls. in 24 hours, the author adopted the 18-in. diameter for the wood and the 16-in. for the steel, and the incidental broken gradient, in preference to a pipe of uniform diameter, because of the great advantage resulting from being able to use a man on the inside of the stave pipe in the process of building; 18 ins. is about the minimum diameter that can be so handled. The advantage consists in the more perfect rounding out of the pipe to its true form that can thus be secured, and the better inspection of all joints.

Clearing, Road Building and Trenching.—As a consideration for right of way and by special arrangement with the property-owners, the timber and brush were cut for a width of 60 ft., and a 16-ft. road with a maximum grade of 10 ft. in 100 was graded out to the corporate

limits of the city, a distance of 4½ miles from the reservoir. Beyond this limit the clearing was made but 20 ft. in width, and only such grubbing done as was necessary for the construction of a narrow road for the delivery of materials and for the trenching. To avoid heavy work in securing suitable grades for the road, all possible advantage was taken of the elevations of the ground for the entire width of the right of way, 60 ft. inside and 33 ft. outside the city limits, the pipe-line location being crossed and recrossed for this purpose. This method entailed much annoyance, difficulty and expense in keeping the road passable after the trench was opened, since much unexpected delay in the securing of materials made it impossible to have them delivered ahead of the trenching. Any other arrangement in such a country was well-nigh impracticable, however, and would have entailed greater expense than that involved in the plan as carried out.

The trenches were staked out for a bottom width of 3.5 ft. for the stave pipe, being widened to 4 ft. on curves, in order to give the room necessary in springing the pipe into line as built. The depth varied from a minimum of 4 ft. to 22 ft. as a maximum, attained in crossing a few sharp points. For the steel pipe, the bottom width was made a foot in excess of the diameter of the pipe, and in all cases the top width was made uniformly 1 ft. greater than the bottom. The material excavated was generally a yellow clay and argillaceous shale, readily moved with mattock and shovel, with occasional short stretches of very soft sandstone requiring the use of some powder to shake it up. The amount of team work in connection with the trenching, other than for back-filling, was very small. Shoring was necessary at but few places, and at these poles cut on the ground answered the purpose.

This work was a part of that undertaken by the contracting firm, the failure of which has already been mentioned, and under its management the road work, clearing, grubbing and nearly three-fourths of the trenching were completed.

Cost.—The contract prices were $50 an acre for clearing, $60 for grubbing, 13 cents per cubic yard for road grading, and 17 cents per cubic yard for trenching, including back-filling.

No especial interest attaches to the actual cost of this work by reason of absolutely incompetent management destroying any value that the figures might otherwise possess. It is sufficient to say that

the cost was greatly in excess of the contract prices. For instance, the actual cost of clearing and grubbing often amounted to fully $300 per acre on a basis of $1 60 per day for labor, while in the trench the men did not average more than 7 or 8 yards a day. The experience of the parties who completed the trenching under the bondsmen of the defaulting contracting firm presents a most forcible example of what efficient management can do, though working at low figures and under most unfavorable conditions. Commencing in October at the beginning of the rainy season, and working much of the time in the mud and rain, this trenching and back-filling was completed at a cost of 17¼ cents per cubic yard with labor at an average price of $1 69 per day, including foreman, nearly 10 yards being moved by each man daily. This cost would have been considerably diminished had there not been much finishing work, very badly scattered, left by the other contractors.

The Wood-Stave Pipe.

Design.—In the design of a wood-stave pipe, the following essential points require consideration: The staves must be thin enough to secure complete saturation and to deflect readily to the degree of curvature employed, and they must be thick enough to prevent undesirable percolation through them. The bands must be of such size that when spaced to secure the desired factor of safety against rupture, there will at the same time be no sensible flexure in the staves and no destructive crushing of the fiber beneath the bands. While fulfilling these conditions, the proportion between the thickness of the staves and the strength and spacing of the bands must be such that the swelling of the wood will not produce injurious strains upon what might otherwise be a properly proportioned band.

The Staves.—The material used for the staves was the native yellow fir. This has been used before for a similar purpose, but the author believes that in each case a much thicker stave was employed. For the Astoria work, the staves were run from 2 x 6-in. stuff with a finished thickness of 1⅜ ins., and twelve staves completed the circle. Lumber wholly free from knots, pitch seams and other defects was specified, and the difficulty experienced in meeting the requirements, especially regarding pitch seams, may be understood from the fact that not over 20% of the lumber sawed from selected logs passed final inspection and went into staves. The outcome was a lot of lumber as nearly

approaching perfection as it is believed has ever been turned out even in the Pacific Northwest. The lumber was about three months from the log when the staves were run, and an allowance of about 2% was made in the width of the staves to allow for seasoning previous to building and for compression in the process of cinching. Staves were run in lots of about 100 000 ft., B. M., as needed, and formed into the pipe with 6 ins. of dirt over it as soon as possible. They varied in length from 12 to 24 ft., and not over 20% were less than 14 ft. in length. They were run with faces true to the circular form of the pipe, with edges on radial lines and a slight projection or bead along the center line of one edge. For pressures up to 80 ft. head, no special attention was paid to the character of the grain, whether slash grain, edge or quarter sawed; but for all greater pressures, while no increase was made in the thickness, only slash-grain staves were used. This action was the outgrowth of observations made on an experimental section. When put under a pressure of 40 lbs. and allowed to remain some days, with an occasional increase by means of a pump to 120 lbs., a few coarse-grained, quarter-sawed staves allowed a perceptible percolation through them at 40 lbs. pressure, and a considerable leakage at 120 lbs. The selecting of the slash-grain staves entailed practically no additional expense, it being attended to when loading at the wharf for delivery on the line.

Bands.—With staves of this character and bands spaced for a factor of safety of about four, it was determined that a $\frac{7}{16}$-in. round band of mild steel upset to $\frac{1}{2}$ in. would properly meet the requirements regarding crushing under bands and flexure in the staves. Eighty-four thousand were used. Steel was specified of a tensile strength of from 58 000 to 65 000 lbs. to the square inch; a limit of elasticity of 30 000 lbs.; an elongation of 25% in 8 ins., and capable of being bent cold and hammered flat without fracture. The following summary of 58 mill tests made by The Osborn Company may be of interest:

	Elastic limit. Pounds per square inch.	Ultimate strength. Pounds per square inch.	Elongation in 8 ins. Percentage.	Reduction in area. Percentage.
Lowest	33 550	59 200	23.75	53.50
Mean	40 850	62 166	26.21	63.30
Highest	50 660	63 810	30.00	70.90

The results, as shown by the record of tests and by examination of the broken test pieces, are very satisfactory, but have evidently been secured by the use of high speed in manipulating the machine. Nuts were used about one-fourth thicker than standard. The completed band, before being sent to the work, was carefully coated with asphalt of such a temper and under such conditions that it withstood the great amount of hammering to which these bands were subjected in the process of pipe building without showing any tendency to fly off; and in the accomplishment of this result only one lot of about 6 000 failed to come up to requirements and was recoated. The author has never been able to understand the reason for the difficulty so often reported from the East, in securing an asphalt coating on iron of such temper as to resist shock, and still not rub off in careful handling.

Clips and Shoes.—The tongues used in making the butt joints were of No. 12 B. W. G. steel, $1\frac{1}{2}$ ins. in width and about $\frac{3}{16}$ in. longer than the width of the stave where inserted ; they were subjected to the kalameining process to render them non-corrosive.

The saddles or shoes are of the type known as the Allen patent, are made of malleable cast iron of excellent quality, and weigh 10 ounces each.

Strain from Swelling of Staves.—Regarding the last of the requirements for the successful design of wood-stave pipe, that the bands be not overstrained by the swelling of the wood, the author is indebted to D. C. Henny, M. Am. Soc. C. E., manager of the Excelsior Wooden Pipe Company, contractor for this work, for the solution of this matter. Mr. Henny has recently conducted some experiments with very ingenious appliances along this line which are of unusual interest. The experiments consist in making actual measurement of the strains induced in the bands of wooden pipe by the swelling of the staves. For this purpose an ingenious device was designed by Mr. Behr, a mechanical engineer of San Francisco. It consists primarily of a very stiff steel spring, resembling a large tuning fork, as shown in Plate VIII, Fig. 1. A hole is bored through both prongs of the fork near its base, through which the end of the band passes after circling the pipe, the nut being then firmly screwed down. A very slight compressing together of the two prongs, either by tightening the nut or by the swelling of the staves, is magnified at the end of the fork. The motion is further magnified by a simple system of levers and

transmitted to an index hand revolving on an arc. By means of a testing machine this arc has been graduated to conform to different pressures, so that it constitutes a spring balance designed to measure heavy pressures with quite a high degree of accuracy, and with a very slight deflection at the point of applying the load. With a tension of 10 000 lbs. on the band, to which the spring is attached, the deflection is but 0.02 in. Two experiments made on independent sections of stave pipe built of kiln-dried yellow fir staves 1⅜ ins. thick, each section being 18 ins. in diameter and 12 ins. long, banded with ½-in. round bands, were conducted in the following manner and with the following results :

SECTION 1.

No. 1. On February 27th, a strain of 4 750 lbs. was applied and the pipe immersed. The following strains were recorded on succeeding dates :

Date......	March 1st.	March 4th.	March 7th.	March 9th.	March 12th.
Strain, lbs.	3 400	2 950	2 750	2 525	2 525

The final strain maintained between the staves was 153 lbs. per square inch of contact.

No. 2. The band was loosened to the strain indicated and immersed again with the following results :

Date.............	March 12th.	March 18th.	March 21st.	March 26th.
Strain, lbs.......	100	1 500	1 500	1 550

The final strain maintained between the staves was 94 lbs. per square inch of contact.

No. 3. The band was loosened again to the strain indicated :

Date.....	Mar. 26th.	Apr. 1st.	Apr. 4th.	Apr. 8th.	Apr. 11th.	Apr. 16th.
Strain, lbs.	500	1 000	1 050	1 100	1 200	1 225

The final strain maintained between the staves was 74 lbs. per square inch of contact. The staves weighed 18 lbs. dry and 27¼ lbs. after the experiment.

SECTION 2.

No. 1. The band was first cinched up to a tension of 5 000 lbs., then loosened to the strain indicated, and the pipe finally immersed:

Date........	Apr. 16th.	Apr. 17th.	Apr. 20th.	Apr. 24th,	Apr. 27th.
Strain, lbs...	450	1 400	1 900	2 000	1 975

Date......	May 1st.	May 4th.	May 7th.	May 10th.	May 13th.	May 17th.
Strain, lbs.	1 900	1 900	1 800	1 700	1 600	1 600

The final strain maintained between the staves was 97 lbs. per square

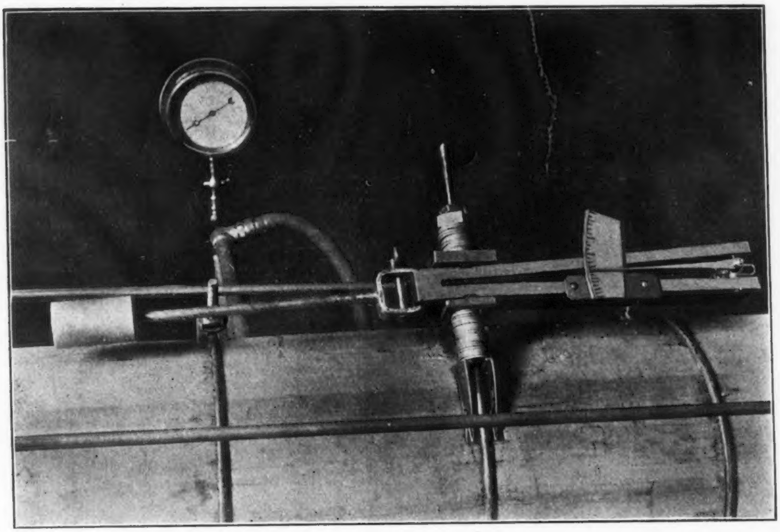

FIG. 1.

FIG. 2.

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inch of contact. The staves weighed 28 lbs. when the experiment was finished, and 20.8 lbs. after being kiln dried subsequently.

These results present an interesting study, but, without enlarging on all they set forth, it is plainly shown that the maximum compressive strain the wood can resist permanently is not much in excess of 150 lbs. per square inch. This fact, since the pressure between the staves must considerably exceed the internal pressure tending to force them apart in order to maintain a tight joint, demonstrates conclusively the limit of safe pressure in wooden pipe construction to be little if any in excess of 100 lbs. per square inch under the most favorable conditions with this class of timber. They also show that when the initial strain is very small the swelling of the staves alone is capable of developing a temporary strain of about 125 lbs. per square inch, a fact which will readily account for the frequent bursting of tanks built with thick staves, and small factors of safety. It will also be observed that, while the pressure is largely self-adjusting, whether a large initial strain is applied in back cinching before filling or the bands but lightly cinched, the former practice seems to insure a somewhat greater permanent pressure between the staves and a correspondingly tighter pipe. So far as these results influence the spacing of bands in pipe construction, they need only be regarded when dealing with low heads and wide spacing, the strains then arising from this source being relatively larger to the bursting pressure due to water head than under any other conditions. In close spacing, the strain from this source falls, of course, below that ordinarily allowed for cinching.

The band spacing employed was as follows:

Head in feet.	No. of bands per 100 ft.	Spacing in inches.	Head in feet.	No. of bands per 100 ft.	Spacing in inches.
0 to 25	100	12	87 to 92	282	4¼
25 " 30	110	11	92 " 98	300	4
30 " 35	120	10	98 " 101	309	3⅞
35 " 40	134	9	101 " 105	320	3¾
40 " 45	142	8½	105 " 109	331	3⅝
45 " 49	150	8	109 " 113	343	3½
49 " 52	160	7½	113 " 117	356	3⅜
52 " 56	172	7	117 " 121	370	3¼
56 " 60	185	6½	121 " 126	384	3⅛
60 " 65	200	6	126 " 131	400	3
65 " 68	208	5¾	131 " 137	418	2⅞
68 " 71	219	5½	137 " 143	437	2¾
71 " 75	228	5¼	143 " 150	457	2⅝
75 " 79	240	5	150 " 158	480	2½
79 " 83	253	4¾	158 " 166	506	2⅜
83 " 87	267	4½	166 " 175	534	2¼

Construction.—J. D. Schuyler, M. Am. Soc. C. E., has so fully described the general method of erecting this class of pipe in his paper on the Denver Water-Works* that it is unnecessary to elaborate it here. A few points only are worthy of mention. Yellow fir, being a hard and rather unyielding wood, tight cinching was the invariable practice; no butt joints were allowed to pass unless fully driven home; bands, shoes and nuts were repainted with asphalt or paraffin paint immediately before covering; back-cinching followed erection on the following day, and back-filling to a depth of 6 ins. over pipe as soon after as possible; all openings in the pipe over 4 ins. in diameter, beside the 4-in. open stand-pipes, were made with special castings and oakum joints 7 ins. in depth, while smaller openings were made by bolting on saddles over lead gaskets, and placing two bands over the top.

Since it is a matter of the utmost importance to the success of this class of work that it be not undertaken by an inexperienced contractor, the specifications excluded the bids of all parties not able to submit satisfactory evidence of their skill and experience in the construction of stave pipe under heavy pressures. Proposals were invited, and payment made on the basis of pounds of steel used in the bands, and feet board measure used in the staves, the price paid for these items representing compensation in full for all expenses involved in supplying these materials and the erection of the pipe complete, exclusive of fixtures, and the back-filling to a depth of 6 ins. over the pipe. The contract was awarded to the Excelsior Wooden Pipe Company, of San Francisco; and to the large experience and hearty co-operation of the company's efficient manager, D. C. Henny, M. Am. Soc. C. E., is due in no small degree the unqualified success of the pipe-laying. This commenced in the latter part of July under some disadvantages, but by aggressive and capable management the work was hurried through to completion in October before the heavy rains had set in.

Tightness.—A test for tightness was made of the upper 2½ miles of this line shortly after the water was first turned in. This gave results which the author believes have never been surpassed in any other pipe construction of any class. The pipe was filled from the head works, and, the gate at the lower end of the section being closed, the water rose and passed off through the overflow from the stand-pipe immediately

* See *Transactions*, Vol. xxxi, p. 135.

adjoining the gate. The head gate was afterward closed. This gate was not absolutely tight, but permitted the passage of a little trickling stream, not exceeding, perhaps, 1 quart in a minute. The assistant engineer in charge of the work was much surprised on the following day to observe this same little trickling stream, apparently undiminished in quantity, passing through the waste pipe at the end of the line. The pipe, contrary to the usual experience with stave pipe, was entirely tight from the beginning, which condition the author largely attributes to hard back-cinching, and the probable absorption of moisture from the damp back-filling. This particular piece of pipe was the only one on the line which permitted a determination of its tightness to be made independently of the steel pipe.

Cost.—The contract prices of the two chief items of this work were: Steel in bands, 4.8 cents per pound; lumber, feet B. M. in staves, measured before milling, $35 40 per M. The average spacing of the bands is $5\frac{9}{16}$ ins. The cost to the city, including all appurtenances, was 90.33 cents per foot, and 76 cents excluding such appurtenances. The whole amount of the contract was $36 100, and the total extra work cost $29 35.

The actual cost of the work the author does not feel at liberty to give by reason of the large personal interest of certain contractors being closely allied thereto. The distribution of the cost was as follows: Building and placing bands, 55%; back-cinching, 26%; repainting iron work, 3%; back-filling to depth of 6 ins. over pipe, 8 75%; placing specials, 3.5%; placing air valve, 0.75%; unclassified labor, 3 per cent.

The rate of wages paid for 10 hours was $1 75 for common labor and an average of $2 71 for foremen. It is presumable that the contract prices represent a profit of from $12\frac{1}{2}$ to 15 per cent.

The Steel Pipe.

Quality of Steel.—The specifications for the sheets used in the manufacture of the riveted steel pipe were the same as those for the bands of the stave pipe, with the exception that the test pieces were to be $\frac{3}{8}$ x 2 ins., and it was to be made by the open-hearth process.

Manufacture.—The sheets were 4 ft. in length. Alternate large and small courses were used, the small courses having the full nominal diameter of the pipe. The last of the eight courses constituting a length of pipe was made slightly conical, so that, being a small course

at the beginning, it was expanded to the size of a large course at the end. The addition of this course was a concession made to the contractor in order to constitute a saving in lead, the specifications requiring a large course at each end, and the addition of two courses making the sections too long for convenient handling or laying. In reality, little advantage was gained by the addition of this eighth course, owing to the difficulty of handling pipes of such length, making connection between them in the trench when using this conical course, and because of the more frequent necessity for cutting pipe in rounding curves. All straight seams were double riveted, and round seams single riveted, the seams being proportioned after Professor Kenneday's formulas for the use of iron rivets. The plates were punched from the sides coming together in the lap. The No. 12 steel was chipped and calked about the union of straight and round seams only, while the No. 10 sheets were beveled, and all seams calked with pneumatic calkers. Each length of pipe was required to pass through the testing machine, and to be tight under the following pressures: 14-in. pipe of No. 12 steel, 200 lbs. per square inch; 16-in. pipe of No. 12 steel, 175 lbs. per square inch; 16-in. pipe of No. 10 steel, 230 lbs. per square inch.

The author had some doubt as to the possibility of making riveted pipe of such light steel perfectly tight before dipping, under the pressures specified, and the manufacturers objected most strenuously to testing every piece.

In practice it was found that by putting every piece through the test, all spurting streams could be eliminated. Mere dropping was not regarded as serious in view of the coating still to be applied, and could not be wholly prevented. By insisting upon strict compliance in the matter of test, it is believed that very superior work was secured; such results as to tightness could scarcely have been secured, however, had not red lead been used in the lap on all joints. After test, the pipes were subjected to an asphalt bath applied under the customary conditions, and a most satisfactory coating was secured. By actual experiment it was found, after a very leaky pipe was coated, it could not be made to leak under any pressure short of bursting.

Joints.—The joints were made by the use of welded iron sleeves $\frac{3}{8}$ in. in thickness, 6 ins. in width, and having a lead space of about $\frac{3}{8}$ in. A reinforcing thimble of No. 8 steel, 8 ins. in width, was inserted half its width at the shop and riveted in one end of each pipe.

Oakum was only used to fill the crack at the junction of abutting pipe, none being used in the joint proper, the annular space being run entirely full of lead.

Cost.—Nothing of special interest attaches to the laying of this pipe, and by reason of inefficient management, coupled with much rainy weather, the cost to the contractor just about equaled the price received, which included laying and back-filling 6 ins. over the pipe. The price per foot paid by the city and the cost of the pipe to the contractor at the wharf were as follows:

Size.	Contract price.	Cost of pipe to contractor.
14-in.	No. 12.. $1 10	$0.85
16-in.	No. 12.. 1 18	.90
16-in.	No. 10.. 1 38	.10

The cost of manufacturing this pipe was about 0.45 cent per pound for labor only, including the work of dipping.

Pipe Line Fixtures.

Blow-Offs.—On the 18-in. pipe the blow-offs are all 6 ins., and on the smaller sizes, 4 ins. in size. They are provided with flanged gates and tangential connections, and are riveted to the steel pipes, while special castings are used for the stave pipe.

Overflow Waste.—A simple combination of stop gate with a relief overflow and stand-pipe is located on certain summits, by means of which the water can be partially or wholly turned off without in any way interrupting the continuity of the flow in that part of the line above the gate, thus rendering any overstraining of the pipe from undue pressure an impossibility. The height of the hydraulic gradient is also rendered adjustable within certain limits, whereby the stave pipe may be kept filled at all stages of flow. The stand-pipe also serves to admit or release air from the summit on which it is located, as may be required. An air valve connects with the pipe below the stop gates, for the purpose of admitting air when the water is drawn off while the gate is closed, as shown in Fig. 2.

Air Valves.—The air valves are the invention of Mr. Thomas W. Brooks, of San Francisco, and have been but recently brought into use. The author desires to testify to their satisfactory performance. They are made with two types of interchangeable valves; one is a wooden ball with vulcanized rubber covering, and the other is a me-

tallic valve having a concave lower surface. They remain open by their own weight until closed by the internal pressure; and are instantly opened by any tendency to a vacuum within the pipe. They require practically no attention, and the water may be turned in or out of the pipe line with impunity, and without fear of interruption from air, either from within or without. An angle valve operated by hand provides for the release of any air accumulating while the line is in operation. The air valves have been arranged in groups of several of small size instead of one of large size, and are so proportioned that a sudden breaking of the pipe at the most dangerous points will not bring an atmospheric pressure on the pipe in excess of about 8 lbs. A suitable stop gate makes possible the removal of any of the valves without interruption to the flow.

Open stand-pipes are used in preference to air valves where practicable.

Suitable manholes of brick masonry, with wooden covers well fastened on, are built over all air valves, blow-offs and stop gates.

Capacity of the Pipe Line.—Just previous to the determination of the leakage in the reservoir, an 18-hour test was made to determine the delivering capacity of the pipe line. The measurement was made in the reservoir, it being empty at the beginning. Observations were taken of the height of the water surface once during the test, and again at its close. The results in the two cases showed a constant rate of inflow. The results computed from the total inflow were as follows:

Volume inflow in 18 hours....................	3 077 170 galls.
Rate " " 24 "	4 102 893 "
Add for loss by reservoir percolation..........	13 560 "
Total capacity of line in 24 hours.............	4 116 453 "

The loss by percolation is assumed to be constant for all depths, which assumption is, of course, not strictly correct, but the error is so small that its practical importance is nil. The rate of delivery promised the Commission was 4 000 000 galls., the amount made the basis of calculation was 4 050 000. The excess of delivery over the amount assumed in computation is about 1.6 per cent.

Determination of Leakage in Pipe Line.—To determine the amount of loss in the pipe line, the water was turned out of the settling basin until the indicated flow over the weir and into the pipe line was at the uniform rate in 24 hours of 326 690 galls., less a percentage of error in

the weir of 9 147 galls., making the net inflow at rate of 317 543 galls. The rate of flow at the lower end of the pipe line, after a lapse of sufficient time for the water to attain its uniform minimum flow, was determined by measuring it in the steel tank in the gate well. The following results were secured:

	To top of second course.	To end of experiment.
Depth of water................	9.19 ft.	17.11 ft.
Volume........................	447.92 cu. ft.	843.45 cu. ft.
Time of filling, in minutes......	19.18	36.10
Rate of inflow in 24 hours......	251 540 galls.	251 660 galls.
Add for average leakage through gates of tank...............	1 410 "	1 410 "
Net rate of pipe line discharge..	252 950 "	253 070 "

Net rate of pipe line discharge taken at 253 010 galls.

Apparent loss in line 317 543 — 253 010 = 64 533 galls.

In view of the fact that observations on a long section of the stave pipe when first filled showed it to be entirely tight, and that it has been necessary to correct quite a number of leaky lead joints on the steel pipe, even in places where the pipe was put under pressure and made entirely tight before covering, as was the case with almost all of it, it is believed that this loss must be accounted for by the existence of leaks of some magnitude in these lead joints, which the saturated condition of the ground at this season of the year has prevented being yet discovered. However the percentage of loss is believed at present to be smaller than is usually obtained in lines of similar length.

Determination of Frictional Loss in Pipe Line.—The existence of the open stand-pipes on the line afforded an excellent opportunity for the accurate determination of the loss of head between them. The following observations were made when the line was discharging its full capacity, 6 369 cu. ft. per second.

Station.	Actual Length.		Observed height in stand-pipe.	Elevation, computed.	Fall per 1 000 ft.
	Stave.	Steel.			
540			572.61	572.65	
	4187.66				1.9628
498.35			564.39	564.30	
	19130.56				1.9628
		16416.38			5.0023
144.25			444.72	444.50	

These are all the measurements which have been completed up to the present time, with the exception of an attempted determination of the fall in the hydraulic grade line between the settling basin and the stand-pipe at station 540. The result was a verification of that obtained between stations 540 and 498.35, but is omitted by reason of an uncertainty amounting to a few tenths of a foot in the entry head at the basin. It will be noticed that the fall used on the hydraulic grade line in construction was 2 ft. per 1 000 for the stave pipe, and 5 ft. per 1 000 on the riveted steel pipe. The almost exact coincidence between these figures and those actually assumed by the flow in the pipe is certainly remarkable, especially in a pipe line so frequently compounded. and where curvature is so freely used. The differences between actual and computed heights of water in the stand-pipes will be seen to vary from 0.04 to 0.22 ft., differences which are quite within the range of probable error in average level work. It will also be noticed that the greatest variation, 0.22 ft., occurs at station 144.25 after the water has passed from the previous stand-pipe through four different sections of 18-in. stave pipe and three sections of the 16-in. steel, in all aggregating about 7 miles. The actual frictional head per 1 000 ft. in the stave pipe is seen to be 1.9628 ft. In determining the loss of head in the steel sections, this value is assumed for the stave pipe between stations 498.35 and 144.25, making the frictional loss in the steel 5.0023 per 1 000 ft.

Substituting these results in the Chezy formula for the stave pipe, $c = \frac{v}{\sqrt{r\ s}} = \frac{3.605}{0.02713} = 132.88$, from which the value of the frictional coefficient n of the Kutter formula for c is deduced to be about 0.00985; and for the steel pipe:

$$c = \frac{4.584}{0.04175} = 109.80 \text{ from which } n \text{ is about } 0.0113.$$

Engineers will not fail to note the large advantage in small frictional loss possessed by the stave pipe over the steel, and to observe that the value of 0.010 for n, used by many engineers in dealing with stave pipe, is here found to be practically correct.

The author commends the result obtained from the steel to the consideration of those engineers who advocate tremendous allowances for friction in pipe of this character compared with those for cast-iron pipe; and as a whole, the results obtained, to the consideration of other engineers who have held that large shortages in delivering

capacity of gravity pipe lines may be accounted for by failure to avoid up and down hill travel, and in not accepting the alternative of heavy pressures and proportionally increased cost incident to more uniform grades on valley routes. That the present discharging capacity of the steel pipe will remain constant through a period of many years the author does not expect, while the almost perfect condition of the inside surface of the wrought-iron pipe taken up from the original pipe line, after carrying Bear Creek water for twelve years indicates that there will probably be no very serious falling off.

The Reservoir.

The reservoir has a capacity to the level of the overflow pipe of 6 250 000 galls., and has a depth of 17.4 ft. to be the flow line,fand 20 ft. to the top of the parapet wall. The general shape is that of the hill on which it was built. The embankment is quite uniformly about 5 ft. in height on the inner slope, except at one point where it is 15 ft. in height. The remainder is in excavation. The top of the bank is about 23 ft. in width; and varies from 0 to 35 ft. in height above the toe of the outer slope. Both inner and outer slopes were intended to be 2 to 1, but the disposal of a considerable quantity of surplus material left the outer slope in places somewhat steeper than this.

Excavation.—The materials in which the excavation was made consisted of much black indurated clay, and a fine grained sand mixed with clay, which in places approached soft sandstone in character. All material was plowed, and when broken was in excellent condition for handling with wheel scrapers. When excavated, it possessed just the right degree of moisture to solidify to the best advantage without the addition of water. All surface soil containing roots or other vegetable matter was first removed, and care taken to secure a proper bond between the natural ground and the made earth. The banks were carried up in layers 6 ins. in thickness, and were thoroughly rolled with a smooth roller weighing 3 000 lbs. to the lineal foot. On the inner slope the bank was made 1 ft. wider than the finished work, and afterward dressed to the proper plane. By the use of slope boards and lines, the whole inner surface was dressed very truly to the desired form without any after-filling being necessary. The price paid for the excavation, 15 cents per cubic yard, included the clearing of the site, previously covered with burned timber, and the construction of the embankments.

The cost to the contractor, 16.9 cents, was needlessly large, as the haul was made unnecessarily long during much of the work, and a scarcity of ready cash made it difficult for the contractors to get rid of worthless men. The total amount of excavation was 49 540 cu. yds.

The Lining.

On the bottom, the reservoir is lined with 6 ins. of concrete laid with expansion joints, $\frac{3}{8}$ in. of cement mortar, one coat of liquid asphalt, and one asphalt coat of harder consistency. The slope lining consists of 6 ins. of concrete laid with expansion joints, one coat of asphalt, one layer of brick laid flat after dipping in hot asphalt, and a final finishing coat of asphalt.

The parapet wall surrounding the reservoir is 2 x 4 ft. in section and built of basalt, with rough rubble backing and squared face stones. It is surmounted with a 9-in. course of coping stone, on which is erected an iron picket fence 5 ft. in height.

General Design.—In the design of this reservoir the author endeavored to secure a lining which would at a reasonable cost fulfil the following somewhat ideal conditions: It should not readily break down over slight local settlements; if it did break down the impervious surface should bend down and not break. It should not crack from expansion and contraction, but if it did crack, no leakage should occur. It should be permanent, and, finally, it should be practically water-tight. The lining adopted is believed to meet all of these conditions. The author has tried reservoir linings made by laying brick dry on a layer of coarse underdrained gravel, and then coating it with asphalt; of asphalt mastic covered with asphalt, of brick laid in cement mortar and coated with asphalt, and of asphalt directly on concrete. All have proved sufficient for the purpose, and some of them especially useful as expedients where large results were required from small expenditures, but he feels that the lining adopted for the present work more nearly meets all the requirements of an ideal reservoir lining than any other with which he is familiar. The cost per square foot, without profit, was as follows:

Slope.	
6 ins. concrete	$0.1187
First coat asphalt 0.649	0.01005
Brick in asphalt	0 08886
Second coat asphalt 0.851	0.01307
Chinking crevices	0.00300
Ironing	0.00356
Total	$0.23724

Bottom.	
6 ins. concrete	$0.10311
Cement mortar finish	.01126
First coat asphalt 0.537	.00768
Second coat asphalt 0.573	.00821
Total	$0.13026

Average cost for the entire reservoir, $0.17965 per square foot.

Concrete.—The concrete is composed of crushed basalt rock, $2\frac{1}{2}$ ins. in maximum size, quarried and crushed near the work; Columbia River gravel, a very clean fine black gravel containing much coarse sand; fine sharp sand, and imported Portland cement, principally Jossen. One cubic yard of concrete contained 0.9 cu. yd. of crushed rock, 0.5 cu. yd. of gravel, 0.1 cu. yd. of sand, and one barrel of cement.

All mixing was done by hand on movable platforms in $\frac{1}{2}$-cu. yd. batches. Three gangs were usually employed, each having six mixers, who also placed the concrete for the two men engaged in finishing and tamping. The coarser rock were raked forward and down, leaving the finer material at the surface, and a long straight edge was used in securing a uniform surface. All three gangs were served by nine wheelbarrows, five handling rock; three sand and gravel, and one, cement. A helper at the cement, one man tending water, one sprinkling concrete already laid, and the water boy, made up the concrete force. The sand, gravel and cement being first thoroughly mixed, water was then added, mixed and spread, and the wet stone added. It was then turned three times on the mixing platforms, and once more when deposited. On the slopes a rough finishing coat was applied as soon as the batch was in place, by the application with a shovel of a little mortar taken from the next mix. A very good surface, smooth and free from stones was thus secured for the laying of the brick, while the comparative roughness of the surface gave the asphalt coat a very perfect adhesion.

On the bottom, the $\frac{3}{8}$-in. finishing coat of cement mortar was applied as fast as the concrete was placed by two finishers using smoothing trowels, who were served by four men mixing and carrying. The mortar was mixed in the proportions of two to one of fine sand and cement. In all concrete work no more water was used than was necessary to mix properly, only a very little showing on the surface when tamped. When the ground was hot and dry, water was sprinkled on it in advance of the concreting. On the slopes the concrete was placed in sheets 10 ft. wide, extending up and down the slopes. On the bottom it was placed in squares measuring 20 ft. on a side. These boundaries were maintained when placing concrete by means of a 2 x 6-in. plank, the straight edge being used between these in securing a uniform surface. When connection was made between sheets the 2 x 6-in. plank was replaced with a piece of beveled $\frac{1}{2}$-in. ordinary weather boarding,

4 ins. in width. After the concrete had thoroughly set, about two weeks after placing, these strips were removed, and in making application of the first coat of asphalt, the grooves were run full. There was no difficulty in removing the beveled strips, but some strips with vertical sides and an occasionally inverted beveled one proved exceedingly troublesome. Plate VIII, Fig. 2, illustrates the appearance of the reservoir during the progress of the concrete work.

Expansion Joints.—These expansion joints have fulfilled every expectation. Not a crack has appeared anywhere in the concrete. Their operation was very noticeable during warm weather, especially in the bottom. In the cool early morning they were much depressed, while in the heat of mid-day they presented the appearance of ridges discernible clear across the reservoir, the amplitude of the motion being in many cases fully ⅜ in. Observations made by the author on a large concrete-lined reservoir, recently built without any provision for expansion and contraction, in which cracks had formed up and down the slope for a distance of several hundred feet at remarkably uniform intervals of about 25 ft. leads him to think about 20 ft. a suitable maximum spacing for expansion joints in concrete laid in this climate. By reason of its superior elasticity the author considers the use of pure asphalt of medium hardness much superior to any mixture of asphalt and sand for this purpose, with suitable provision for holding it on the slope, and doubts the efficiency of a mastic unless made very rich in asphalt.

Cost of Concrete.—There were 603.3 cu. yds. of concrete used on the slopes, which cost the contractor $1.072 a yard for labor and $1.939 for materials, except cement, which was furnished by the city, and cost $2.822 per yard of concrete. The amount of concrete on the bottom of the reservoir was 678.2 cu. yds., and cost the contractor $0.674 per cubic yard for labor and $1.923 for material, except cement; this was furnished by the city and cost $2.641 per yard of concrete. The contract price was $3 50 per yard, exclusive of cement. The total cost of the cement coating was $1.126 per 100 sq. ft. That the work was well managed is apparent from the fact that 1.84 cu. yds. of concrete was mixed and placed each day for each man employed. On the bottom alone, this amount was increased to 2.35 cu. yds. For work of this character the author considers this a creditable showing, for he has known instances where the labor account amounted to four times as much on

work of a similar character but larger proportions. For most of this work Italians were employed who were experienced in concrete work. The crushed rock was secured from a quarry located about 800 ft. from the reservoir, at about the same level, and delivered on the work at a cost of 95.28 cents per cubic yard. The sand and gravel were dredged from the Columbia River and delivered by sub-contract at the wharf at a cost of 86.59 cents per cubic yard.

Cement.—The city purchased by contract all the cement used on every part of the work at a cost of $2 45 per barrel delivered at the wharf, as needed on the work. In all about 3 100 barrels were used, of which 1 558 went into the reservoir lining. Most of this was of the Jossen brand, and was of a superior quality. Every sixth barrel was tested for tensile strength, with frequent tests for blowing, and time of setting. Only seven barrels were rejected, these having deteriorated by exposure to weather.

The Asphalt Work.—The asphalt used in the work was all of the Alcatraz brand. Two grades were employed: the L (liquid), and XXX (paving cement). The first is a natural liquid asphalt, and the second is the product of refining the natural rock asphalt with about 20% of the liquid as a flux. Both grades are now placed upon the market in barrels holding about 400 lbs. As a rule no asphalt was applied to the concrete until the latter had been in place fully two weeks, and was well dried on the surface, though some slight variation from this rule was unavoidable by reason of the work being overtaken by the fall rains before completion. On the bottom was first applied a coat of the L grade, which was followed by a coat of the XXX paving cement. On the slopes none of the L grade was used by reason of the tendency to creep, which a soft underlying coat always produces, and so often mars the appearance of work on reservoir slopes. The author, after a considerable experience in using asphalt in different ways as a reservoir lining, is disposed to believe that any advantages possessed by a soft coat over a harder one, as a first application, is more fancied than real. At the proper temperature, the harder grade runs just as readily, and enters all crevices just as surely when applied, and if the masonry be entirely dry and clean, and preferably a little rough, it adheres more tenaciously than the liquid. The only superiority possessed by the latter as a first coat is that if it must be applied on a damp surface, it will adhere where the other will not.

All dust was carefully swept from the concrete, as it effectually prevents any bond, and the asphalt was applied with mops made from twine used in the local salmon fisheries. The mops were served from large sheet-iron buckets, which were kept filled by attendants, who carried asphalt from two large kettles holding about 3 000 lbs. each, in which it was melted and kept at the proper temperature. The bricks used on the slopes were about half vitrified and half common, the contractors being disappointed at the last moment in the delivery of the requisite number of the former. As laid they were submerged in a bucket of hot asphalt, and placed in position on the slope by means of iron tongs. Sufficient asphalt always streamed from the brick to fill entirely all irregularities beneath it. A push joint was made, much as when laying brick in cement mortar, but much more expeditiously. For the sake of close joints and consequent economy in the use of the asphalt, it proved very important to keep the temperature high enough for the asphalt to run like water, which is the manner in which it should always be used to secure the best results. Common laborers could, with a little practice, when well supplied with materials, readily lay an average of 2 300 bricks in 10 hours. The finished coat of asphalt followed as speedily after the brick laying as possible, in order to avoid delay from rain, as the water standing in unfilled joints dried out very slowly. In applying this coat an effort was made to fill all joints, and where this could not be done with hot asphalt on a slope, a rich mastic of sand and asphalt was used. This much improved the appearance of the work, as the brick were quite rough and somewhat irregular in shape. The connecting joint between the top of the lining and the base of the parapet wall was also run full of asphalt. A final smoothing was given the finished surface by going over the slopes with hot irons. Although the general appearance of the surface was by this means much improved, the author is rather loath to trust hot iron in the hands of common laborers on an asphalt surface. Unless most carefully watched, overheating and consequent serious injury are almost certain to occur. When this lining had been exposed to the rays of the sun for a considerable time, there was a very noticable sliding of the brick on the slope, and a consequent closing up of the joints, crowding out the asphalt where they were thick by reason of the asphalt having been used too cold on days that were too windy to permit it being

maintained at a proper temperature. As a consequence, openings were produced between the brick lining and the wall at the top of the slope, which were filled with mastic. The footing course of brick was prevented from sliding by being set into the concrete of the bottom lining. After a few weeks all motion ceased entirely.

In order to secure the best results possible, all asphalt work should be performed during the dry summer months. Such was the plan for the Astoria work, but the delay in beginning carried the date of completion over into the rainy season. By careful management in keeping the work in proper shape for speedy drying, no especial difficulty was experienced except with the brick. Although they were housed at the reservoir, and piled and fired when rained on during transportation, sufficient moisture was apparently absorbed from the air to produce by evaporation small bubbles or blisters on the surface when dipped in the hot asphalt. No similar difficulty was experienced with brick laid during the dry weather. This defect is one of appearance rather than reality, and is but temporary, as the steam soon condenses and the bubble collapses. Although the adhesion between the brick and the asphalt is sometimes destroyed over the limited area covered by these bubbles, the effect is simply to permit these brick to become more quickly saturated than would otherwise be the case. It must not be assumed, as has been so often stated, that asphalt renders anything wholly impervious to water, or is of itself impervious. On the contrary it may be readily demonstrated by a simple experiment that a brick thoroughly coated and recoated will in time absorb as much water as an uncoated one. The advantage of the asphalt lies in its retarding effect on the passage of water ; it does not exclude it.

Cost of Asphalt Work.—Tables Nos. 1 to 7, inclusive, showing the amount, cost and distribution of both labor and materials employed in the asphalt work, are prepared in a way that is believed to make the probable cost of other similar work easily determinable. In view of the interest which the use of this material as a reservoir lining is very properly creating among engineers, especially in the East, this presentation may not be untimely.

Iron Fence.—On top of the coping which surmounts the parapet wall is erected an iron picket fence 5 ft. in height, having pickets ½ in. square, spaced 4 ins. between centers. The rails are small channel irons 2 ins. in width. No attempt is made at ornamentation. The

panels are 8 ft. in length, and at the end of each a post picket extends 4 ins. into the stone. Each post is braced from the face of the wall, the brace also having a tie fastening into the top of the wall, making three drilled holes necessary for each panel. The panels are supported half way between the posts. Both supports and braces are made adjustable by means of movable clips and set screws, rendering possible the securing of perfect line and grade. All joints were made with lead and calked. This fence was designed and made by the Van Dorn Iron Works, of Cleveland, and was erected by day labor under the supervision of one of the assistant engineers, without a foreman, at a cost of $985 40 for a total length of 917.2 lin. ft.

Aerating Fountain.—At the center of the reservoir is a 12-in. entry pipe leading from a connection with the gravity conduit in the power house, and passing up through a concrete pedestal. It terminates a little above the surface of the water in a brass fountain head, having about 300 holes, ranging in size from $\frac{1}{16}$ to $\frac{9}{16}$ in. in diameter, arranged in concentric rings with the larger at the center, and gradually diverging from the perpendicular to an extreme angle of 35° on the outer circle. Through this the water may be turned from the pipe line, when not used for the development of power, and the reserve head may be used in the formation of an aerating fountain. Its construction was a natural consequence of having a reserve head for power development. It proved a very ornamental feature, and is expected to be useful in securing aeration and free circulation in the water, which is necessarily heavily charged with vegetable matter, and, when allowed to stand in a reservoir without circulation for a considerable time in the summer, has developed very offensive qualities.

At the foot of the fountain pedestal, in the 12-in. supply pipe, is a stop gate, and a double nozzle fire-hose connection for the purpose of securing streams for cleaning out the reservoir.

Total Cost of Reservoir.—The total cost of the reservoir, exclusive of iron fixtures, which are included in the cost of the gate and power house, is summarized in Table No. 8.

Reservoir Leakage.—When first filled, careful observations were made to determine the rate of leakage from the reservoir. The depth of water was about 14 ft.; the time elapsing between the observations was 68 hours. As the air was in a state of saturation all the time there was no occasion to make deductions for evaporation. The rainfall

record was taken from the reports of the local signal service. The results were as follows :

Total rainfall .... 7 384 cu. ft.
Total quantity retained .... 2 253 "
Total leakage .... 5 136 "
Total leakage in gallons in 24 hours..13 553 galls. per 24 hours.
Total leakage in gallons in 24 hours per 1 000 sq. ft. of lining submerged, 232.1 galls.

Assuming the absence of evaporation, and that the rate of leakage is uniform for all depths, it would require a term of years for the reservoir to empty itself in this way, since the average rainfall is 75 ins. For a new reservoir filled for the first time, and with consequently no opportunity for sedimentation, the results are gratifying. A second experiment of similar nature, made a few days later, gave results identical to the preceding.

The Power and Gate House.

There is a surplus fall in the mile of 14-in. steel pipe at the end of the conduit which is to be used for the development of power by Pelton wheels for the operation of an electric plant for the illumination of the streets and public buildings and for pumping a water supply to the districts not capable of being supplied directly by gravity.

The Building.—The gate house for controlling the water at the reservoir and the power house for the light and pumping plant have been united in one building of basalt masonry, with cut face stones laid random, and rubble backing. It has a copper roof, is sealed throughout the lower story with red wood, finished in the natural grain, and has three living rooms finished off upstairs for the residence of the keeper. The end enclosing the gate well is semi-circular in form. The building as a whole presents a pleasing effect, which should be credited to Mr. J. E. Ferguson, the architect.

Arrangement of Power-House Fittings.—The arrangement of the power-house appliances may be readily understood from the plan (see Fig 3). The water passes directly through the building to the fountain in the reservoir. When the power is utilized for work, the fountain is cut out and the water discharged through the nozzles of either of the Pelton wheels. The tail water is conducted the length of the building

in a concrete channel under the floor and discharged into a 14-in. pipe leading into the gate well. It will also be noticed that provision is made for connecting the suction of the pump to be installed later directly to the pipe under the same pressure as the nozzle operating

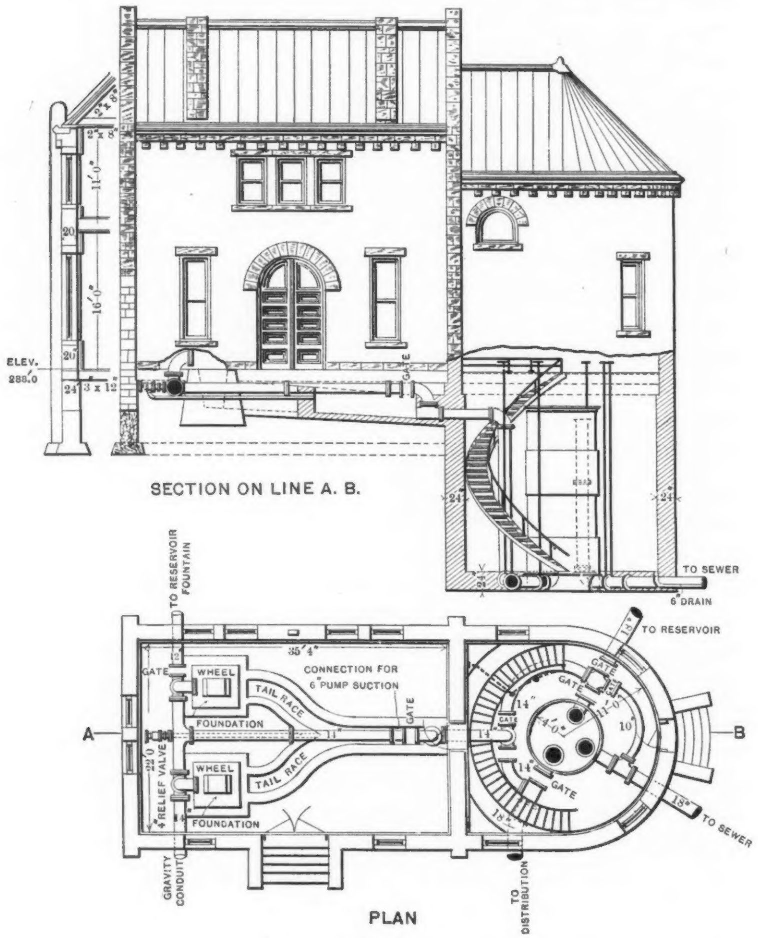

FIG. 3.

the wheel which is to drive the pump, thus diminishing by that amount the work necessary to be done in elevating the desired amount of water, which will never exceed 200 000 galls. in 24 hours. When the flow at the power-house is entirely stopped for any reason, and the

water allowed to waste through the overflow at the head of the 14-in. line, a 4-in. relief valve discharging into the tail race affords a safeguard against any ram likely to be produced in the closing of the gates.

The Gate Well.—Fig. 3 gives a very good idea of the general arrangement of the gate well. It is 22 ft. in clear diameter, and is lined with 2 ft. of concrete. In the center of the well is a steel tank 8 ft. in diameter and 21 ft. in height, built of $\frac{1}{4}$-in. plate. This tank has pipe connections with the reservoir, the distribution and the sewer, and indirectly with the tail race from the Pelton wheels, through which the flow of the pipe line can also be turned independently of the wheels. All surplus water passes through this tank to the waste through the open stand-pipe, the top of which stands at low-water mark for a full reservoir.

From the arrangement of connections and gates, it will be seen that the reservoir or the tank may be temporarily cut out without affecting the supply to the distribution. The overflow is always operative whether the reservoir is in use or not, and the fresh water from the pipe line will always first meet the demand from the distribution, until the supply is exceeded, when the reservoir is drawn upon for the deficiency. A cylindrical brass screen, not shown in the drawing, is inverted over the distribution supply pipe in the tank. This screen can be cleaned at any time by reversing the flow through it. Two feet of concrete is placed in the bottom of the well, enclosing the fittings, and constituting the bottom of the tank. An independent drain pipe provides for the discharge of all seepage water from the well. A spiral iron stairway, supported on the wall by brackets, affords a convenient means of entering the well, while the tank may be entered from above by a stationary iron ladder down the inside. All gates are operated from above by means of hand wheels supported on vertical gas-pipe shafting.

The total cost to the city of the buildings and fittings was $10 177 25.

The Tunnel.

The tunnel through which the distributing system connects with the new reservoir extends directly north from the gate house through the intervening ridge, and is about 1 200 ft. in length. Of this distance, the first 300 ft. from the gate house averages about 20 ft. in depth below the surface, and was tunneled by the contractor in prefer-

ence to digging open trench. The remaining 900 ft., except for a portion which is through solid rock, is lined with concrete and terminates in a manhole at each end.

Excavation.—The 300 ft. at the south end, which was afterward refilled, was driven through a rather soft argillaceous yellow and blue shale. The remainder, with the exception of about 250 ft. of solid rock near the center of the tunnel, was through an exceedingly hard, compact black shale, which required powder for its removal and rapidly disintegrated when exposed to the air. Timbering was necessary everywhere except in the solid rock section, and consisted of 6 x 6-in. posts and caps, 2 x 12-in. sills and 2-in. lagging. The posts were usually spaced 2 ft. between centers, and were not infrequently crushed in by the swelling of the material, in places where there was apparently no tendency to cave. In places where water penetrated in considerable quantities, the disintegration was so rapid that the tunneling was done with great difficulty, and though timbering was kept close up, several bad caves occurred.

FIG. 4.

The rock was very hard basalt, and was worked entirely by hand. Air was supplied by an exhaust fan operated by an electric motor taking current from the wire of an electric street railway. Driving was usually conducted from both ends. The section driven throughout was 5 ft. 5 ins. in width by 6 ft. in height.

Lining.—It was the original intention to put in a lining of brick with vertical sides and arched top, but the material penetrated proved disappointingly unstable, and the completion of the tunnel driving was so long delayed by reason of the quantity and hardness of the rock encountered, and by the failure of the original contractors, that the work of lining was necessarily performed long after the heavy fall and winter rain had rendered the ground very treacherous, so that it was found inexpedient to remove all the timbers in very many places. It was accordingly determined to use a strong concrete section for the lining, and leave in much of the timbering. Fig. 4 shows the form of section adopted, and the disposition made of the posts in order to

secure a sufficient thickness of concrete between them and the forms without removing them, the earth being dug away from behind them at the foot of each, and the post pushed back out of the way. The forms were built in 4-ft. sections for the sides, and 2-ft. lengths for the top, and were held in position by 1 x 4-in. bracing on the inside. The concrete was well rammed into all crevices, except at the upper corners, and where considerable caves existed, which were filled back of the concrete with the excavated material. The proportions used in the concrete were the same as those used in the reservoir work, with the exception that the screenings were not removed from the rock. The work of lining in the north end was much delayed by reason of the large amount of digging necessary in securing proper line and grade, this matter having been very carelessly looked after by the men doing the driving. The work in its completed condition is in a very satisfactory shape, which result has been secured only by most untiring supervision.

Cost.—The work passed through many vicissitudes, being at different times under the management of three different contractors and subcontractors. The excavation in the softer materials was not well handled. The rock excavation and concrete work were well managed, and the cost very carefully kept. The cost of the tunnel to the contractor and to the city is given in Table No. 9.

Tunnel Pipe.—The main supply pipe from the new reservoir to a connection with the high-service distribution is 18 ins. in diameter. That in the part of the tunnel which was refilled, and that which lies without the tunnel to the north, is of cast iron $\frac{25}{32}$ in. thick, while the portion lying within the permanent tunnel is wood-stave pipe. Little room was left in the concreted section for the building of pipe, but it was accomplished without difficulty, the gang making an average of 132 ft. a day.

Distributing System.

The distributing system as at present arranged is divided into a low and a high service, the low being supplied from the small reservoir of 500 000 galls. capacity built by the Columbia Water Company at a flow-line elevation of 167 ft.; and the high service being supplied from the new reservoir previously described.

The New Service.—The street mains in the low service range in size from 6 ins. to 14 ins., and in their arrangement and size are designed to

secure a delivery in case of fire in any of the business portions of the city of 2 000 galls. per minute, in addition to the ordinary domestic consumption, at an effective pressure of 80 lbs. at the hydrant nozzles. Part of the pipe is cast iron, and part steel kalamein pipe.

Astoria has no sea wall, and many of the streets in the business part of the town are supported on pile trestles about 18 ft. high. On these streets the kalamein pipe is used by reason of its lightness and greater adaptability to withstanding vibration than the cast iron. Wherever supporting ground exists, cast-iron pipe is used. The kalamein pipe is supported below the street surface on timbers dapped into and bolted to the piles, and is boxed with 2-in. lumber, the box for the 12-in. pipe being made without a cover. The gauges are the customary standards used by the manufacturers of this class of pipe: 6-in., No. $11\frac{1}{2}$; 8-in., No. $10\frac{1}{2}$; 10-in., No. 10, and 12-in., No. 8.

The hydrants on these streets are connected with the street mains by a section of similar pipe, having a cast flange attached to each end, the pipe being expanded like boiler tubes with a hammer to fit the slightly rounded inner edge of the flange, thus removing any possibility of the hydrant being pushed off by the pressure, while a lead joint provided at the outer end of the flange makes the connection water tight. The cast-iron pipe is all of the hub and spigot type of the following thicknesses:

Diameter, inches......	14	12	10	8	6
Thickness, "	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{1}{2}$

At the foundry frequent tests of the quality of the metal were made by the inspector with the following results:

		Pounds per square inch.
Test piece, 1 in. square.....	Least strength......	18 500
	Greatest "	29 500
	Average "	22 000
Test piece, $\frac{13}{16}$ in. round.....	Least "	19 000
	Greatest "	32 000
	Average "	26 500

Test bars 1 × 2 ins., 24 ins. between supports, load applied at center.

	Breaking load.	Deflection.
Least....................	2 000 lbs.	$\frac{1}{4}$ in.
Greatest.................	2 700 "	$\frac{3}{8}$ "
Average..................	2 230 "	$\frac{11}{32}$ "

All pipes were tested to 300 lbs. pressure, and well hammered during the process. Asphaltum was used for coating. The special castings were all made after special drawings, thus dispensing with the unnecessary length and weight of most foundry patterns. Pipes were laid with 3 ft. of earth cover, and with 2 ins. of lead in the joints.

The High Service.—The old pipe taken up from the gravity line of the old works and from the old distribution is largely used for the high service. The former is lap-welded wrought iron supplied with the Converse lock joint, and the latter is principally cast iron of the ordinary hub and spigot type, of a thickness suitable for about 150 ft. head. The pipe for this service ranges from 6 to 10 ins. in size. Before laying it was all cleaned with steel wire brushes, tested under hydrostatic pressure, and recoated with asphalt.

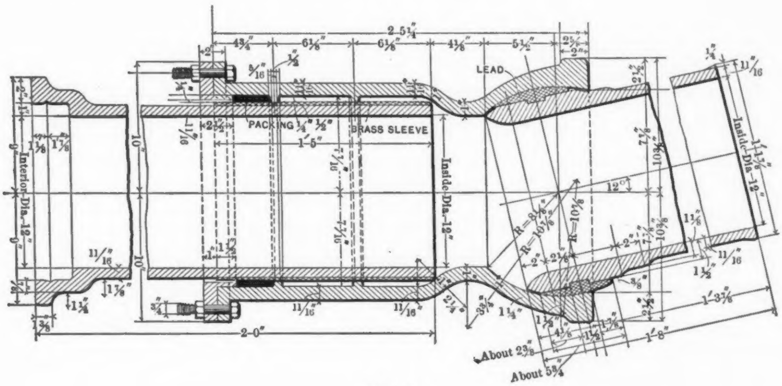

FIG. 5.

Hydrants and Gates.—The gates are all of the Ludlow make, and are so distributed as to permit a line to be cut out without disturbing the rest. On the trestled streets, beside being placed at intersections, they are put in every two blocks as a safeguard against loss of pressure by the falling of street mains in event of an extended conflagration. All were tested to 300 lbs. pressure, and are provided with adjustable cast-iron gate boxes. The hydrants are of the Watrous type, much resembling the Mathews, have 6-in. connections with street mains, and 5-in. clear valve openings, and are provided with two 2½-in. hoze nozzles, and a 5-in. steamer nozzle. They also were tested to 300 lbs. pressure.

Flexible Slip Joints.—In some sections of the town the ground is of a very sliding character, the street improvements at some of these points being gradually pushed out of line as much as 2 ft. in a year. In the laying of the street mains, these sections have usually been avoided. It was necessary, however, that about 1 000 ft. of ground of this character be crossed with a 12-in. pipe. To meet the difficulty, a combination slip and flexible joint was devised, shown in Fig. 5. These were distributed at intervals of about 200 ft., and the pipe enclosed for a distance of 50 ft. on each side with a covered wooden box, considerably larger than the pipe, in order to give room for motion, without the pipe having to take the weight and friction of the earth. The ball and socket joint is patterned after the New York City standard, and was so nicely turned that when stood on end, the lead space held water wholly without leakage.

Fire Gates.—Mention has been made that in case of fire, the pressure is secured through the high service from the new reservoir, by the opening of two fire gates which connect the low with the high service at two extreme points, and by automatically cutting out the lower reservoir by means of a check valve in its supply pipe. These fire gates are of the ordinary Ludlow piston lift type, one 14 ins. and the other 10 ins. in diameter, and are both opened and closed from the central fire station by opening and closing an ordinary stop-cock at the end of a line of ordinary ¾-in. service pipe leading to a patented governor attached to each of the gates. This governor was especially designed by the author to meet the conditions here existing, where the lower reservoir elevation was sufficient for ordinary domestic consumption, but insufficient for a really good fire protection directly from the hydrants, while the upper reservoir was at a suitable elevation for a first-class fire pressure, 113 lbs., but objectionably high for domestic use. The device is suited for operating from a distance any piston lift gate working in a pipe under pressure. It would seem to be an economical and efficient arrangement for the speedy closing of gates in large principal supply mains in case of disastrous breaks such as not infrequently occur. It has worked in the present instance without any failure from the beginning, and has proved very certain in action. Its operation is simple, and is readily followed by the aid of Fig. 6. *A* is connected with the pressure pipe or main in which the gate is placed which is to be operated by the governor, *B* with the lower end of

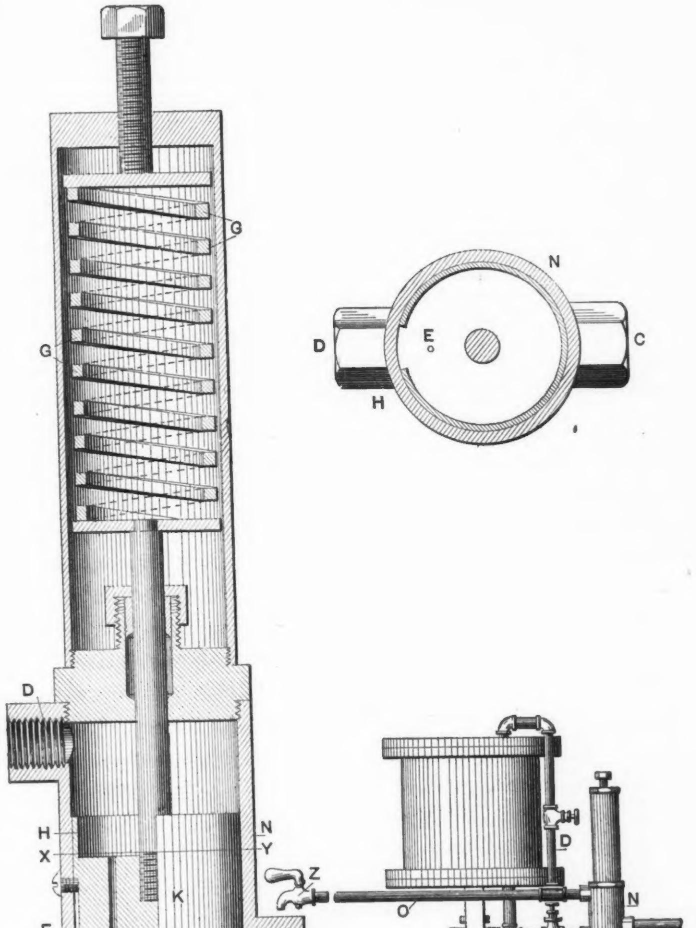

FIG. 6.

the gate cylinder, C with the waste, D with the upper end of the cylinder, with a T connection, in one branch of which is connected the small pipe O leading to the fire station from which the gate is to be operated. At the end of this pipe is placed a stop-cock or other convenient means of opening and closing this pipe. Under normal conditions the pipe is closed, the water has free access from the pressure pipe P through A, E and D to the upper end of the gate cylinder, thus acting on the gate piston and keeping the gate closed. There being an equilibrium of pressure in the two ends of the governor cylinder, the spring G keeps the piston at the lower end of the cylinder. When it is desired to open the gate, the pipe at the fire station is opened, releasing the pressure at D, causing the governor piston to be thrown to the upper end of the cylinder, which act closes D and opens B to the passage of the water from A. The water acts on the lower end of the gate piston, causing the piston to rise and the gate to open, while the water from the upper end of the gate cylinder passes off through the pipe O at the fire station. By closing the pipe at the fire station, equilibrium is again gradually restored between the two ends of the governor cylinder through the opening E, when the spring G throws the piston to the lower end of the cylinder, releasing the water from the lower end of the gate cylinder through the pipes and movable port B, C and F, leaving the gate free to close with the pressure again restored to the upper end of its lift cylinder. By reversing the connections, it will be seen that a gate can be always kept open instead of closed while the cock at the controlling station is kept closed. As set up, a pair of 1½-in. flanges holding a wire screen are inserted in the pipe A to prevent any obstruction getting into the opening E.

Conclusion.

In concluding this paper, no instructive lessons can be recorded which are drawn from any failures unanticipated or otherwise, since in every particular the work has been free from experiences of such a nature, and has in all respects accomplished all that was either promised or anticipated. This result the author feels should be very largely attributed to that wisdom which secured as commissioners men of sound judgment, good business sagacity and sterling integrity, and which removed them as a body beyond the pale of political influence. Not the least of their acts of wisdom which contributed to the success

of the work was their recognition of the responsibility which rested upon the chief engineer, by leaving him entirely untrammeled in the selection of his assistants and the managing of his department. This leads the author to the pleasant task of here recording his sincere gratitude to the engineers associated with him, for their manifestation of high ability, untiring energy, and loyal co-operation in securing the largest measure of success possible. Among those to whom he is much indebted are James D. Schuyler, M. Am. Soc. C. E., who reported on the plans for the work in the fall of 1894, and to whom he is under obligations for many excellent suggestions; R. C. Gemmell, M. Am. Soc. C. E., who, as a partner, was associated with the author in the early preliminary work on plans and specifications; A. S. Riffle, M. Am. Soc. C. E., mechanical assistant on construction, and assistant engineer in charge of reservoir, gate and power house, and tunnel; J. F. Case, assistant engineer in charge of pipe line and head works; George A. Shields, shop and foundry inspector and assistant engineer in charge of the distributing system, and Lars Bergsvik, in charge of construction surveys.

TABLE No. 1.—Cost of Asphalt Coat on Slope Concrete—29 637 Sq. Ft.

Labor.	Total.		Total cost.	Total cost per square foot.
	Hours.	Rate.		
Buildings, sheds, etc.	....	....	$5.00	$0.000168
Spreading	91	At $0.20	18.20	0.000614
Boiling	91.5	" 0.15	13.72	0.000462
Attendance	73.5	" 0.15	11.025	0.000372
Sweeping	49.5	" 0.15	7.425	0.000251
	305.5			
Material.	Quantities.			
Asphalt	19 243 lbs.	" 0.01225	235.729	0.007950
Haul	9.6 tons.	" 0.4700	4.500	0.000152
Fuel	1.0 cord.	" 2.50	2.500	0.000084
Totals	....	....	$298.102	$0.010053
Contract price	....	....	$657.94	$0.022222

TABLE No. 2.—Cost of First Coat of Asphalt on Concrete Bottom—34 454 Sq. Ft.

Labor.	Total. Hours.	Total. Rate.	Total cost.	Total cost per square foot.
Building sheds	25	At $0.20	$5 00	$0.000146
Spreading	38	" 0.20	7 60	0.000220
Boiling	37	" 0.15	5 55	0.000161
Attendance	43	" 0.15	6 45	0.000186
Sweeping	44	" 0.15	6 60	0.000191
	162			
Material.	Quantities.			
Asphalt	18 490 lbs.	" 0.01225	226 50	0.006578
Haul	9.25 tons.	" 0.470	4 35	0.000126
Fuel	1.0 cord.	" 2.50	2 50	0.000073
Total cost			$264 55	$0.007681
Contractor's price			$765 58	$0.0222222

TABLE No. 3.—Cost of Second Coat of Asphalt on Bottom—34 154 Sq. Ft.

Labor.	Total. Hours.	Total. Rate.	Total cost.	Total cost per square foot.
Building sheds			$5 00	$0.000146
Spreading	35	At $0.15	5 25	0.000153
Boiling	30	" 0.15	4 50	0.000132
Attendance	52.5	" 0.15	7 88	0.000230
Sweeping	44.5	" 0.15	6 68	0.000195
Foreman	17.5	" 0.25	4 38	0.000128
Material.	Quantities.			
Asphalt	19 591 lbs.	" 0.01225	239 99	0.007019
Haul	9.8 tons.	" 0.470	4 61	0.000134
Fuel	1.0 cord.	" 2.50	2 50	0.000073
Total cost			$280 79	$0.008210
Contractor's price			$758 90	$0.022222

TABLE No. 4.—COST OF LAYING DIPPED IN ASPHALT ON SLOPE BRICK —132 000 BRICK, 29 637 SQ. FT.

LABOR.	TOTAL.		Total cost.	Total cost per "M."
	Hours.	Rate.		
Unloading brick from barge......	290	At $0.15	$49 00	$0.37122
At wharf......................	22	" 0.25		
Haul and storage at the Reservoir......	160	" 0.35	152 43	1.15473
	140	" 0.55		
	129.5	" 0.15		
Laying......................	561	" 0.15	84 15	0.63750
Attendance......................	1 341	" 0.15	201 15	1.52387
Briding asphalt......................	220	" 0.15	33 00	0.24999
Foremen......................	96	" 0.25	24 00	0.18180
	2 959.5			
MATERIAL.	QUANTITIES.			
Brick at......................	....	" 7.00	924 00	7.00000
Asphalt......................	93 372 lbs.	" 0.1225	1 143 81	8.66516
" haul......................	46.7 tons.	" 0.47	21 95	0.16628
Total cost......................	....	....	$2 633 49	$19.95055
Contract price......................	57 000 75 000	....	$2 500 50	$21 50 17 00

TABLE No. 5.—COST OF ASPHALT FINISHING COAT ON BRICK SLOPE LINING, 29 637 SQ. FT.

LABOR.	TOTAL.		Total cost.	Total cost per square foot.
	Hours.	Rate.		
Building sheds, etc......................	....	....	$5 00	$0.000168
Spreading......................	95.75	At $0.15	14 36	0.000485
Boiling......................	73.25	" 0.15	10 99	0.000371
Attendance......................	144.50	" 0.15	21 68	0.000732
Sweeping......................	20	" 0.15	3 00	0.000101
Foreman......................	60	" 0.25	15 00	0.000505
	393.5			
MATERIAL.	QUANTITIES.			
Asphalt......................	25 230 lbs.	" 0.01225	309 07	0.010425
Haul......................	12.6 tons.	" 0.47	5 92	0.000199
Fuel......................	1.0 cord.	" 2.50	2 50	0.000084
Totals......................	....	....	$387 52	$0.013070
Contract price......................	....	....	$657 94	$0.022222

TABLE No. 6.—COST OF FILLING WITH MASTIC CREVICES IN FINISHED BRICK SLOPE, 29 637 SQ. FT.

LABOR.	TOTAL. Hours.	Rate.	Total cost.	Total cost per square foot.
	146	At $0.15	$21 90	$0.000738
	130	" 0.15	19 50	0.000657
Attendance and sweeping........	56	" 0.15	8 40	0.000285
Foreman........................	30	" 0.25	7 50	0.000250
	362			
MATERIAL.	QUANTITIES.			
Asphalt........................	2 813 lbs.	" 0.01225	34 46	0.001164
" haul.....................	1.4 tons.	" 0.47	0 66	0.000022
Fuel...........................	1.0 cord.	" 2.50	2 50	0.000084
Total cost.....................	....	....	$87 92	$0.003

Contractor's price included with coating.

TABLE No. 7.—COST OF IRONING SLOPE, 29 637 SQ. FT.

LABOR.	TOTAL. Hours.	Rate.	Total cost.	Total cost per square foot.
Ironers........................	29.55	At $0.15	$44 33	$0.001496
Heaters........................	75	" 0.15	11 25	0.000380
Sweeping and attendance........	34.5	" 0.15	5 18	0.000174
Foreman........................	49.5	" 0.25	12 37	0.000418
	454.5			
MATERIAL.	QUANTITIES.			
Irons..........................	20	" 1.50	30 00	0.001012
Fuel...........................	1.0 cord	" 2.50	2 50	0.000084
Total cost.....................	....	....	$105 63	$0.003564

Contractor's price included with coating.

TABLE No. 8.—Cost of the Reservoir. Capacity, 6 203 000 Galls.

Items.	Amount.	Total contract price.	Total cost to contractor.	Additional cost to city.	Total actual cost.
Excavation..............	49 540 cu. yds.	$7 431 00	$8 371 99	....	$8 371 99
Concrete on slope........	603.3 " "	2 111 55	1 816 19	$1 702 75	3 518 94
" " bottom......	678.2 " "	2 373 70	1 761 83	1 790 95	3 552 78
" in pedestal....	18.0 " "	63 00	69 11	44 10	113 21
" " tunnel......	12 6 " "	44 10	34 41	30 87	65 28
Cement coating, bottom..	341.54 squares	....	129 63	254 80	384 43
" " pedestal.	3.00 "	....	4 07	2 45	6 52
1st coat asphalt slope.....	29 637.0 sq. ft.	657 94	298 10	....	298 10
2d " " "	29 637.0 " "	657 94	387 52	....	387 52
1st " " bottom...	34 454.0 " "	765 58	264 55	....	264 55
2d " " " ..	34 154.0 " "	758 90	280 79	....	280 79
Brick lining............	132 0 M	2 500 50	2 633 49	....	2 633 49
Mastic on brick lining...	29 637.0 sq. ft.	....	87 92	....	87 92
Ironing slope............	29 637.0 " "	....	105 63	....	105 63
Parapet wall.............	289.0 cu. yds.	1 445 00	1 304 73	475 58	1 780 31
Iron fence..............	917.2 lin. ft.	....	....	985 40	985 40
Riprapping bank........	....	....	....	36 23	36 23
Fixing road............	....	....	....	17 40	17 40
Cleaning up............	....	....	59 82	....	59 82
Grading around reservoir	800.0 cu. yds.	120 00	85 00	....	85 00
Office buildings, etc......	....	....	64 18	....	64 18
Water supply and main..	....	....	288 00	....	288 00
Total..............	....	$18 929 21	$18 046 96	$5 340 53	$23 387 49

TABLE No. 9.—Cost of Tunnel.

Items.	Quantities.	Total cost to contractor.	Total contract price.	Additional cost to city.
Earth excavation..................	963.5 cu. yds.	$1 795 43	$963 50	
Timbering......................	....	587 38	837 00	
Earth excavation, north approach..	157.0 cu. yds.	37 00	157 00	
Earth excavation, south approach..	....	120 57		
Cleaning and relagging..........	....	16 50		
Rock excavation..................	296.7 cu. yds.	3 230 68	519 23	
Concrete lining..................	563.5 "	2 252 27	3 381 00	$1 161 30
Total cost..................	....	$8 039 83	$5 857 73	$1 161 30

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AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

PAPERS.

SOME GENERAL NOTES ON OCEAN WAVES AND WAVE FORCE.*

By THEODORE COOPER, M. Am. Soc. C. E.

TO BE PRESENTED MAY 20TH, 1896.

A wave in a general sense has been defined as a state of disturbance propagated from one part of a medium to another. Through the oscillatory action of the particles of the medium, the energy due to a disturbance is transferred from one point to another. There is not, necessarily, a transfer of matter through the action of a wave, though in some cases the wave displaces, usually to a small amount only, the medium through which it passes. Currents, on the other hand, imply the passage of matter associated with energy.

Waves may be free or forced. A free wave is one which is no longer acted upon by the disturbing influence, either through the cessation of the disturbance or through the wave having outrun the sphere of disturbance. A forced wave is one upon which the disturbing influence continues to act so as to modify its propagation.

* A large portion of the following article has been collated from various sources at different times, and is not claimed by the author as original.

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

Thus, while a gale is blowing the character of the water wave is continually being modified ; beyond the immediate influence of a gale, or after it subsides, regularly oscillating waves or rollers. are obtained, for the long ones not only outstrip the shorter ones, but are less speedily worn down by fluid friction.

The ocean tide is mainly a forced wave, depending on the continued action of the moon and sun. The tidal wave in an estuary or river is practically free, being almost independent of moon and sun, and depending mainly upon the configuration of the channel and the tidal disturbance at the mouth.

In the Thames, the mean range of the tide at Sheerness is about 13 ft.; at Deptford, about 17; at London Bridge, about 15; and from this point it diminishes gradually to the weir at Teddington where it is 2 ft.

At the entrance of Bristol Channel the whole rise at spring tides is about 18 ft.; at Swansea, about 30 ft., and at Chepston, about 50 ft.

At the entrance of the Bay of Fundy, the currents are very rapid, but the range is only about 8 ft.; at the head of the bay, where it branches into two shoal arms, the range of the tide sometimes amounts to 60 to 70 ft.

At Cherbourg, it is only 15 ft., but at St. Malo it rises nearly to 40 ft.

The most usual division of free waves is into long waves, oscillatory waves and ripples. The first two classes run by gravity and the third mainly by surface tension. Long waves, or waves in water that is very shallow, compared with the length of the wave, are due to disturbances which extend to the full depth of the water. Oscillatory waves are due to disturbances confined to the upper layers of the water, which die away with great rapidity in successive layers below.

Mr. Scott Russell called the long wave a " wave of translation," in contradistinction to a " wave of oscillation." Under waves of translation he included the tidal wave, bores,* ordinary ground swell and waves

* Airy says: "We believe the following description of the cause and appearance of the bore will be found correct. It is necessary for its formation that there be a very large tide rising with great rapidity (thus at Newnham, where the water rises 18 ft. in an hour and a half, the bore is considerable). It is necessary also that the channel of the river be bordered with a great extent of flat sands near to the level of low water. These circumstances hold in the Severn, the Seine, the Amazon, the bays at the head of the Bay of Fundy (Chignecto Bay and Bay of Mines), and other places where the bore is remarkable. When the rise of the tide begins, the surface of the water is disturbed in mid-channel, but the water is not broken, it is merely a common wave. But as this rapid rise elevates the surface suddenly above the level of the flat sands the water immediately rushes over them with great velocity and a broken front, making a great noise. This is the whole of the bore; it is, however, a majestic phenomenon."

of oscillation when they reached much shallow water. Under waves of oscillation he included all other storm waves.

This classification has been adopted by many subsequent writers. This division, however, has no value as a classification, and is very apt to induce erroneous ideas on the action and power of waves. It is recognized now that all storm waves are waves of translation to a more or less extent, according to the strength of the wind, the time it has been blowing, and other circumstances.

Mr. Scott Russell, in describing his wave of translation, says:

"As the wave advances the particles of water of which it is composed, instead of continuing to travel forward themselves, force other particles upwards into the wave and themselves subside and take the place of these latter particles. These again behave themselves similarly, depositing themselves in the place of further particles; and in this manner the wave proceeds constant in shape and velocity but continually recomposed of new particles of water which are successively lifted up, carried forward and let down again into new positions.

"A solitary wave of elevation obviously carries across any fixed transverse section a quantity of water equal to that which lies above the undisturbed level. If the wave had been one of depression, the translation would have been in the opposite direction to that of the wave motion. Hence, when the wave consists of an elevation, followed by a depression of equal volume, it leaves the water as it found it."

The theory of motion of such a wave is based on the hypothesis that all the particles in a transverse section have at the same instant the same horizontal speed, the vertical motion of the water depending on the change of horizontal speed from section to section. The speed of propagation of such a wave of translation is given by Mr. Scott Russell as that which would be acquired by a body falling through half the depth of the water,

$$V = \sqrt{g\,h}$$

h being the depth of water measured from the wave crest.

Rankine states that long waves or waves in water that is very shallow compared with the length of the wave have a velocity nearly independent of the wave length and nearly equal to that acquired by a body falling through a height equal to half the depth of the water added to three-fourths of the height of the wave.

$$V = \sqrt{g\,(h^1 + \tfrac{3}{4}\,D)},$$

h^1 being depth of still water and D the wave height.

These two formulas are identical, for the wave crest is about three-fourths of the depth of the wave above still water, so $h = h^1 + \tfrac{3}{4}\,D$.

The tidal wave travels at different speeds in different seas and oceans, dependent upon the depths of the sea. In the North Sea it travels 45 miles per hour. The Atlantic tidal wave (long wave) passes over 90° of latitude in 12 hours, or at a rate of speed of 520 miles per hour. The great earthquake wave of 1868 was estimated to have traveled in the Pacific Ocean at a rate of 300 to 400 miles per hour. The great wave formed in the Straits of Sunda by the volcanic eruption of Krakatoa was felt upon the coast of France, and its speed estimated at over 300 miles per hour.

The nearest example to a typical oscillatory wave is found in what is called the swell, or regular rolling waves, which continue to run in deep water after a storm. In a pure oscillatory wave, the motion of each particle is in nearly a circular orbit; the particles at the surface of the water describe the longest orbits; the extent of the motion, both horizontal and vertical, diminishes in a geometrical progression as the depths increase in arithmetical progression and at great depths the motion is insensible.

Fig. 1 is Weber's diagram of an oscillatory wave, Fig. 2 showing the same filaments in still water, $O\ O$ being the level of the surface in still water. The particles of water are rotating to the right in circles whose radii vary from r equal R for the surface particles, to r^1 equals $\frac{r\,k\,e}{R}$ for all particles at a lower depth, k being the depth of the filament below still water, e the base of the Naperian logarithms, and r and R as given later.

The trachoidal lines O, a, b, c, etc., in Fig. 1, represent the form taken by the filaments O, a, b, c, etc., in Fig. 2 during the passage of a wave. The left-hand portion of Fig. 1 shows the distortion of the filaments, both horizontally and vertically, this being greatest at the surface and diminishing rapidly as the depth increases. The wave is traveling to the right, or in the same direction as the particle at the top of its orbit. The energy imparted to the particles is expended in lifting the particle the distance of its center of rotation above its position at still water, and in giving it rotation about the center. It can be shown that one-half of the energy of disturbance goes to lift the particle to its mean height and one-half to impart rotation.

Figs. 3 and 4 have been prepared to show the form of wave generated when the particles travel in elliptical orbits. Both the waves

shown are generated by the same ellipse, but the wave length in Fig. 4 is made double that of Fig. 3.

The following formulas (condensed by Prof. C. S. Lyman) are those giving the relations between the elements of such an oscillatory wave:

l = length of wave from crest to crest.

D = depth from trough to crest.

V = velocity of propagation of the wave.

t = period or interval of time between consecutive wave crests.

r = radius of orbit of a particle at the surface.

v = velocity of a particle on its orbit or at the crest of a wave.

R = radius of circle whose circumference is a wave length, also the length of a pendulum keeping time with the wave.

a = elevation of crest above still water.

b = depression of trough below still water.

g = acceleration of gravity.

$$l = t\,V = 2\,\pi\,R = \frac{g\,t^2}{2\,\pi} = \frac{2\,\pi\,V^2}{g}.$$

$$D = 2r.$$

$$t = \sqrt{\frac{2\,\pi\,l}{g}} = 2\,\pi\sqrt{\frac{R}{g}} = \frac{l}{V}.$$

$$V = \frac{l}{t} = \frac{g\,t}{2\,\pi} = \sqrt{\frac{g\,l}{2\,\pi}}^{*} = \sqrt{g\,R} = \frac{g\,r}{v}.$$

$$v = \frac{2\,\pi\,r}{t} = r\sqrt{\frac{g}{R}} = r\sqrt{\frac{2\,\pi\,g}{l}} = \frac{V\,r}{R} = \frac{2\,\pi\,r\,V}{l} = \frac{g\,r}{V} = \frac{t\,g\,r}{l}.$$

$$a = r + \frac{\pi\,r^2}{l} = r + \frac{r^2}{2R}\,;\; b = r - \frac{\pi\,r^2}{l} = r - \frac{r^2}{2R}.$$

Sine of angle of steepest slope is sin. $\theta = \frac{2\,\pi\,r}{l} = \frac{r}{R}$.

$R : r = g : \frac{4\,\pi^2\,r}{t^2}$, or as gravity is to the centrifugal force of a surface particle.

The maximum height of a wave depends on the centrifugal force of the particles, and thus on the external forces generating it. When the centrifugal force becomes equal to gravity, or $r = R$, the resultant force for a particle at the highest point of its orbit or at the crest of the

* $V = \sqrt{\frac{g\,l}{l\,\pi}}$ is the velocity due to a heavy body falling $\frac{l}{4\,\pi}$ or as it is sometimes worded, approximately one-thirteenth of the wave length.

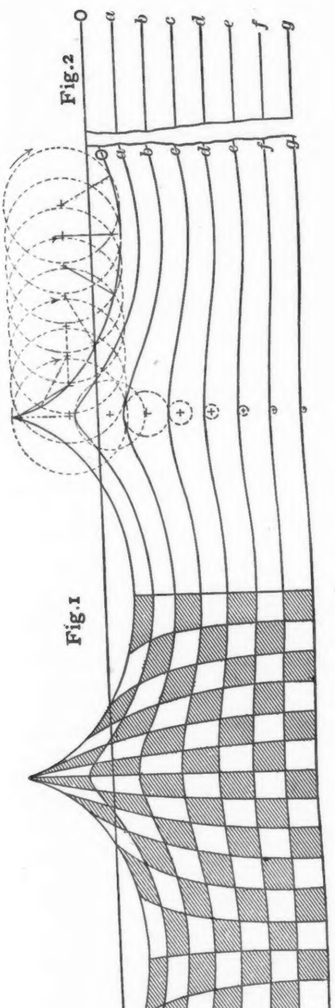

Fig.2

Fig.1

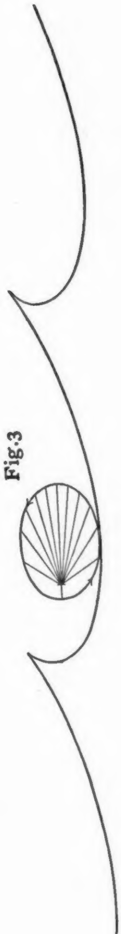

Fig.3

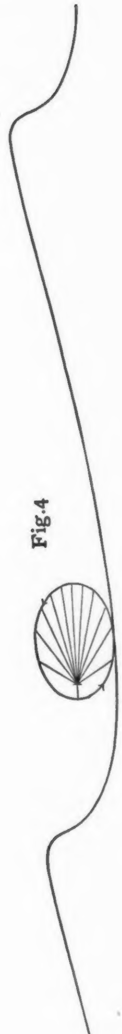

Fig.4

wave must be zero. Beyond this point the particle flies from its orbit and the crest breaks into foam.

The greatest elevation of the crests above the level of still water is also when $r = R$ and equals three-fourths of the depth of the wave, and the centers of the orbits of the surface particles will be on a line one-fourth of the depth of the wave above the level of still water.

Capt. Gaillard, from 45 observations on waves 2½ to 6 ft. deep just before breaking, found that the elevation above still water varied from 0.67 to 0.89, with a mean of 0.76; with a flat slope of the bottom and opposing wind it was increased, while with a steep slope and favorable wind it was decreased.

Stevenson says waves at Wick's Bay were two-thirds above and one-third below mean level.

Rankine gives elevation of crest above still water $= \frac{D}{2} + 0.7854 \frac{D^2}{l}$

depression of trough below still water $= \frac{D}{2} - 0.7854 \frac{D^2}{l}$

The height of the wave is, within certain limits, independent of its length.

The longer waves travel the faster.

The normal oscillatory wave to which the preceding theoretical equations apply is the wave on deep water or water more than a wave length in depth. In shallower water the orbits are no longer circles, but approximately ellipses of less height than length according to the degree of shallowness.

When a series of waves advances into water gradually becoming shallower, their periods remain unchanged, but their speed, and consequently their length, diminishes and their slopes become steeper. The orbits become distorted in such a manner that the front of the wave becomes steeper than the back, the crest, as it were, advancing faster than the troughs. At length the front of the wave curls over beyond the vertical, its crest falls forward and the wave breaks.

Purely oscillatory waves rarely, if ever, occur in the ocean. They are also more or less waves of translation. The forward horizontal motion of each particle under the crest is not quite compensated for by its backward movement under the trough, so that the wave sets down each particle of water a little in advance of where it picked that

particle up, causing what is known to sailors as the "heave of the sea." This effect, however, like the whole disturbance, is greatest at the surface layer and diminishes rapidly for each lower layer.

Long waves are analogous to oscillatory waves with the modification that, owing to the enormous length of the waves as compared with the depth of the water, the extent of horizontal motion of the particles is nearly equal at all depths and the extent of the vertical motion in any layer is nearly in the simple proportion of its height above the bottom. The orbit of such particles is a very long and flat ellipse. The deeper a particle is situated, the flatter becomes the orbit, a particle in contact with the bottom moving backward and forward in a horizontal line.

Comparing the equations for the speed of propagation of a long wave, $V = \sqrt{g\,h}$, with that for an oscillatory wave, $V = \sqrt{\frac{g\,l}{2\,\pi}} = \sqrt{g\,R}$, it will be seen that they are very similar in form.

Rankine gives as a general equation for the velocity of waves of all figures and for every kind of disturbance, provided only that the upper surface of the water is free:

$$V = \sqrt{g\,k}$$

k being the virtual depth of uniform disturbance, or, more briefly, the virtual depth, or a depth which, with a uniform velocity equal to the horizontal surface velocity of a particle, would give the same volume of horizontal displacement as occurs at a vertical plane through the crest of a wave with the varying velocities of any wave.

For an oscillatory wave, $k = R$, and for a long wave, $k = h$.

When oscillatory waves pass from deep to shallower water, imparting their energy to a less and less mass of water, and flattening their orbits, they take on more and more the characteristics of long waves. Mr. Scott Russell says that if waves be propagated in a channel whose depth diminishes uniformly, the waves will break when their height becomes equal to the depth of the water. He has never seen a wave of 10 ft. in 10 ft. of water, nor so much as 20 ft. in 20 ft. of water, nor 30 ft. high in 5 fathoms of water, but has seen them approach near these limits.

M. Bazin has shown that a wave breaks when its height exceeds two-thirds of the total depth. The most trustworthy measurements of waves in the mid-ocean show 44 to 48 ft. to be a remarkable height.

Waves having a height greater than 30 ft. are not commonly encountered. Scoresby measured waves 43 ft. high, 559 ft. long, traveling at a velocity of 32½ miles per hour, at 16-second intervals.

Dr. Schott (1891–92) reports the greatest storm wave observed by him as 36 ft. above sea level. Lieut. Paris records 37 feet above sea level. Dr. Schott says the heaviest storm waves he met moved about 58 ft. per second, and attained a length of about 650 ft. He confirms Lieut. Paris' determinations that the proportion between wave height and wave length in a high sea is as 1 to 18, and in a moderate sea as 1 to 33. Capt. Gaillard, from 58 observations at St. Augustine on waves varying from 4 ins. to 6 ft. in height, found that the depth at which waves broke varied from 0.72 to 2.0 times the wave height, but that for the greater number, it equaled the wave height. A strong, favorable wind made it equal 1.25, while an equal wind in the contrary direction caused it to fall to 0.72; when there was no wind and the bottom was uniform and sloping only 1 in 100, the depth was nearly always 1, but when the slope was about 1 in 12, it became 2. Officers of the United States Navy have recorded waves measuring ½ mile from crest to crest and a period of 23 seconds.

Waves having lengths of 500 to 600 ft. and periods of 10 to 11 seconds, are the ordinary storm waves of the Northern Atlantic.

Mr. Deverell observed in the equatorial calms a swell, which was never absent and measured 4 ft. high, 500 ft. long, and had periods of 10 seconds.

The study of waves and wave action is one of great importance to engineers.

The strength, modeling and stability of vessels, the best speed of boats in channels of limited cross-section, the wash of banks in canals and impounding reservoirs, the protection of sea coasts, the improvement and maintenance of channels and harbors, the design and maintenance of artificial structures which are liable to wave action, whether they be inland and subject to the sudden onslaught of a wave produced by the rupture of some restraining medium, or located on the coast and subject to the attack of sea waves—all require a knowledge of water waves and their action.

This paper will be confined to the consideration of the action of waves or the force of the sea upon artificial structures.

Smeaton classed the action of the sea as among the powers of nature

that are not subject to calculation. Since his time, experience with sea structures and knowledge of the laws governing the force of waves have been greatly extended. The valuable collection of facts and experiments by Mr. Thomas Stevenson and others upon the power exerted by sea waves, and the study of the laws governing the action and forms of waves by Messrs. Scott Russell, Rankine, Stokes and many other able investigators, go far to enable a reasonable estimate to be made of the forces to be encountered by structures subject to wave action.

Mr. Scott Russell says:

"In sea works there were practically two classes of waves to deal with. In deep water there were not only the oscillatory surface waves to be encountered, but also those which he had termed 'waves of translation,' forming what were called 'rollers,' or, when on a smaller scale, 'ground swell.' These were a much more troublesome class of waves. It was mainly with them that the engineer had to deal in places open to the Atlantic.

"To reflect or send back the roller was the most effectual plan. For this purpose nothing more was necessary than a deep perpendicular face of perfect masonry, and so long as it stood firm it was faultless, for the reflection really converted the whole effect of the roller on itself into a simple pressure of water. When such a wave was reflected on a perpendicular wall, it merely provided a hydraulic pressure equal to that due to little more than double its own height."

Rankine says:

"When waves roll against a vertical wall they are reflected, and the particles of water for a certain distance in front of the wall have motions compounded of those due to the direct and reflected waves. The particles in contact with the wall move up and down through a height equal to double the original height of the wave."

This is in accordance with well-known mechanical laws. The work stored in a wave must necessarily be measured by the weight of water in the wave, multiplied by the mean distance to which this mass of water has been lifted. The height to which each particle is lifted is determined by the centrifugal force due to the velocity of its rotation. The energy of each particle will be measured by its weight and its velocity of rotation, or, in other words, by its weight and the height to which it will be lifted by the centrifugal force.

To destroy such a wave, each particle must be opposed by a force equal and opposite to that which it has. To reflect or throw it back an additional opposing force of the same amount must be added to it.

A column of water, then, double the wave height would measure the maximum force necessary to reflect the particles in the maximum section through the wave crest. Let Fig. 5 represent a long or solitary wave of elevation (a wave of translation).

$O\ O$ = level of undisturbed water.

a = elevation of wave crest above sea level = $\frac{3}{4}\ D$.

h = depth of water.

V = velocity of propagation of the wave.

v = uniform horizontal velocity of water in the section $A\ B$.

Then $V : v = h : D$ or $v = \frac{V\ D}{h}$, but $V = \sqrt{g\ h}$,

therefore $v = D\ \sqrt{\frac{g}{h}}$.

The vis viva of all the particles in the section $A\ B$ will be :

$\frac{1}{2}\ M\ v^2 = \frac{M g\ D^2}{2\ h}$ where M is the mass of the particles in the section $A\ B$.

$M g = W = \gamma\ h$ = weight of particles in section $A\ B$.

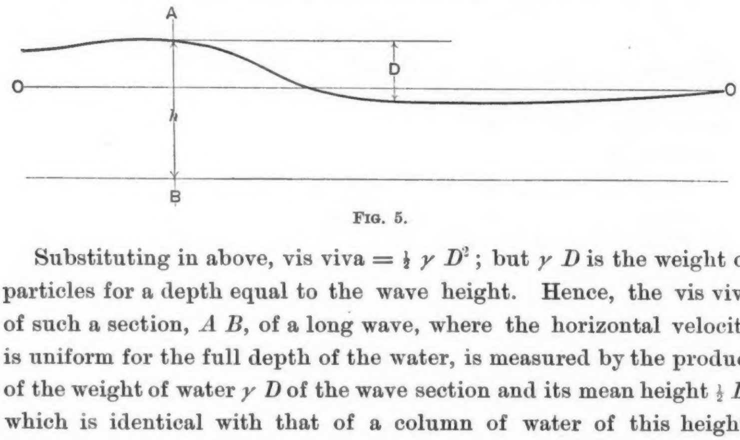

FIG. 5.

Substituting in above, vis viva = $\frac{1}{2}\ \gamma\ D^2$; but $\gamma\ D$ is the weight of particles for a depth equal to the wave height. Hence, the vis viva of such a section, $A\ B$, of a long wave, where the horizontal velocity is uniform for the full depth of the water, is measured by the product of the weight of water $\gamma\ D$ of the wave section and its mean height $\frac{1}{2}\ D$, which is identical with that of a column of water of this height. To destroy suddenly the energy of such a wave, it is therefore necessary to present an obstruction capable of resisting a head of water double that of the wave height.

From the practical side, there is a mass of facts and experiments upon the force exerted by the sea which is very impressive and tends to create doubt in regard to the correctness of theoretical deductions. While theories should be tested and judged by a comparison of their

deductions with observed facts and the results of experiments, these latter should be carefully examined and received with much caution when they appear to contradict well-proved mechanical laws. Before questioning the correctness of the theoretical deductions, it would be well to examine the observations and experiments, to see if there are not other elements to be considered, which would explain the phenomena in accordance with true mechanical principles.

The text-books present as evidence of the enormous power of the waves the experiments of Mr. Thomas Stevenson by means of a dynamometer, the transportation of large masses of rock or masonry, the quarrying of rock from its bed, the great elevations to which spray or even solid water is thrown by the breaking of waves against cliffs or artificial structures, etc. An examination of the recorded facts should be made to see if proper and full consideration has been given to the various elements effecting the interpretation of such phenomena.

Stevenson by means of his marine dynamometer obtained at Skerrymore Rocks in the Atlantic Ocean the following average and maximum results in pounds pressure per square foot of surface exposed.

Average of summer months, 1843 and 1844....	611 lbs.
" winter " "	2 086 "
Maximum, March 29th, 1845................	6 083 "

In the German Ocean he obtained the following pressures per square foot:

Maximum at Bell Rock......................	3 013 lbs.
" Dunbar........................	7 840 "

The dynamometers had disks from 3 to 9 ins. in diameter, but generally 6 ins.; the strength of the springs varied from 10 to 50 lbs. for every $\frac{1}{8}$ in. of elongation.

The pressures obtained by Stevenson are constantly used and accepted as evidence of the force of the waves, and even so careful and reliable an author as Rankine gives them as such, neglecting or overlooking the very important qualifications made by Mr. Stevenson in regard to them.

It is well to note here that Rankine apparently is unwilling to accept these high pressures on any other theory than that the waves did rise high enough to produce such high hydrostatic pressures, for

he says, "the concentration of energy upon small masses of water produces waves of heights greatly exceeding those which occur in water of uniform depth, as the following examples show"; he then tabulates opposite the above pressures the feet of water which would produce them.

The following quotations show Stevenson's own opinion as to the applicability of these pressures as the measure of the wave forces. Referring to his observations, he says:

"It will be sufficient here to state generally the results obtained, only premising that the values refer to areas of limited extent, and are applicable therefore only to the *piece-meal* destruction of masonry, and must not be held as applicable to large surfaces of masonry.

"The experiments at Dunbar and Buckie prove that the sea may exert a force so great as 3½ tons *over the limited extent of surface presented by the disks*, and that the force varies much with the level at which the instruments are set."

The emphasis in all quotations is that of the author quoted.

Clearly, therefore, Stevenson does not accept these dynamometer pressures as the measure of the force of a wave, but solely as local pressures which can be produced by the waves. He gives the following records of great heights to which spray and solid water have been thrown by the action of the sea:

"On February 15th, 1853, during a gale a large body of water was thrown upon the lantern of Nosshead Lighthouse at a height of 175 ft. above the sea.

"At Unst, the most northerly of the Zetland Islands, a door was broken open at a height of 195 ft. above the sea.

"In November, 1827, during a ground swell *without* wind, the water rose to the gilded ball of the Bell Rock lantern 106 ft. It therefore follows that there is a force in action at the foot of the Bell Rock tower competent during ground swells when *there is no wind* to project a column of water to the height of 106 ft., which, according to the laws of hydrodynamics, is due to a pressure of very nearly 3 tons per square foot; whereas, the greatest force that happened to have been actually measured was only 1½ tons.

"It may be added that the spray on an average of 17 observations taken roughly was found to rise on a hollow curved wall about seven times higher than the waves which projected it; and on a vertical wall, taking a mean of 23 observations, it rose 6.6 times."

Now, if it had happened that the water which was thrown to those great heights had been thrown against the surfaces of the disks, the dyna-

mometers, as Mr. Stevenson suggests, would have recorded the much higher pressures due to the height of those columns of water. Such pressures, however, would not measure the force of the waves, for only a small portion of the water in the wave was projected to those heights.

That the energy of a wave, upon meeting an obstacle like a wall or tower, would be expended in giving a greater velocity to those particles near the free surface and in projecting them in the direction of the least resistance, is not mysterious. The action of a hydraulic ram in lifting water higher than the head of the operating current is precisely similar. To determine the energy of such a wave, it is necessary to know not only the number of particles that are raised and their velocities, but also the greatest number of particles that are finally stopped.

That such a concentration of energy into a small portion of the water can cause very high local pressures, which should be considered in the detail of the work is unquestioned, but these pressures cannot be taken as the measure of the effect of a wave upon the stability of a large mass of masonry. They would bear about the same relation to the action of a wave, considered as a whole, as the local action of an engine wheel in crushing or indenting a rail would to the action of an engine or train load upon a bridge structure.

In addition to the records of the dynamometer and of the heights to which water has been thrown, other evidence as to the immense power of the sea has been presented, consisting of the movement of heavy blocks of stone, the breaking out or quarrying of rock from its bed, the breaking of timber booms, etc. The conclusions drawn from many of these instances, where sufficient data have been furnished as a basis of judgment, are, to the author's mind, entirely fallacious.

The cautious investigator would put little reliance on a calculation of the force of a wave from the breaking of wet timbers by repeated blows. The breaking out from their beds of blocks of stone or rock in place by the impact of a wave upon water already contained in the seams is a well-recognized process which in no manner conveys any knowledge of the force of the wave. The movement of masses of rock 6 to 13 tons in weight from their original beds 70 to 75 ft. above the sea level, as noted by Mr. Stevenson at Whalsey Skerries, Shetland, is very impressive. The action, however, is not mysterious, when the immense waves which occur at such places are considered. At Round Island, Scilly Group, large masses of water have been driven over the

summit of this rocky island, which is 130 ft. in height, and small $2\frac{1}{2}$-ounce stones carried to the top of a dwelling house 143 ft. above high water. At Bishop Rock Lighthouse, about 5 miles from the island, waves 50 ft. above high water have been noted. These waves would probably be about $66\frac{2}{3}$ ft. from crest to trough. That waves of this size breaking upon a sloping rock or against a lighthouse should produce the destructive effects recorded is not astonishing, but that writers on wave force should assume these extraordinary results as some inherent force due to waves regardless of their height is surprising.

The author, while accepting all these evidences of the force of the sea at various localities, desires to show that they are due to the size of the waves at each locality, and, therefore, when the actual maximum waves are known, it is possible to estimate the resistance which must be given to every structure to meet the force of such waves.

Mr. Stevenson, after enumerating many wonderful effects of sea waves, all within his own personal observations, says :

"We should never expect that examples of the development of the *greatest* force would be found to be against masonry of those artificial works which form our ports and harbors. Accordingly, the examples of the most violent wave action which have been heretofore mentioned were cases of the dislocation or movement of dislocated natural rocks.

"This, however, no longer holds true. The most startling example now on record is that of an artificial work."

He then describes the Wicks Breakwater and the struggle to maintain it against the sea. For a full report of this work see Mr. Stevenson's reports. It will be sufficient for the present purpose to make the following extracts :

"In December, 1872, an enormous mass of concrete, at the end of the work, weighing not less than 1 350 tons, succumbed to the force of the sea, and the resident engineer actually saw it from adjacent cliffs being gradually 'slewed' round by successive strokes, until it was finally removed and deposited inside of the pier, having sustained no damage but a slight fracture of the edges. It was composed of three courses of large blocks of 80 to 100 tons (see Fig. 6), which were deposited as a foundation on the rubble. Above this foundation there were three courses of large stones carefully set in cement, and the whole was surmounted by a large monolith of cement rubble measuring about 26 ft. by 45 ft. by 11 ft. in thickness, and at 16 ft. to the ton, weighing upwards of 800 tons. This block was built *in situ*. As a

further precaution, iron rods 3½ ins. in diameter were fixed in the uppermost of the foundation courses of cement rubble. These rods were carried through the courses of stonework by holes cut in the stone, and were finally embedded in the monolithic mass which formed the upper portion of the pier."

The shaded portion of Fig. 6 shows the part removed by the waves. This mass weighed no less than 1 350 tons, and presented an area of about 496 sq. ft. to the sea. The lower or foundation course of 80-ton blocks, *b b*, retained their positions unmoved. The second course of cement blocks, *a a*, on which the 1 350 tons rested, were swept off after being relieved of the superincumbent weight, and some of them were found entire near the end of the breakwater.

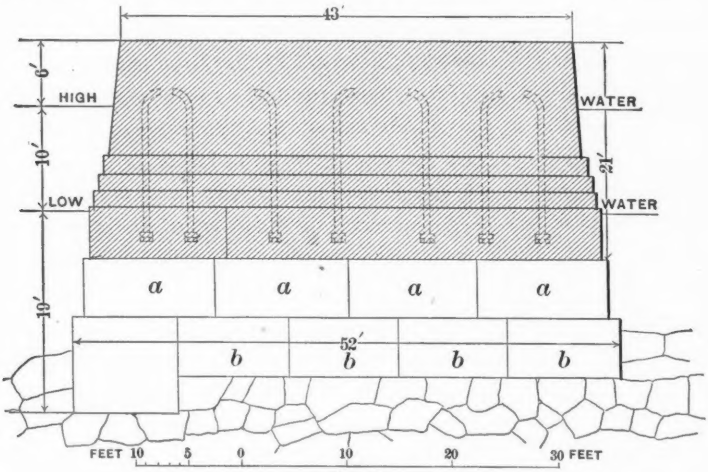

FIG. 6.

The waves by which the works had on various occasions been assailed, and which had carried away the outer portion of the work, were estimated by the resident engineer at 42 ft. from crest to hollow. They passed over the top of the parapet in masses of solid water estimated to be from 25 to 30 ft. deep, and, as ascertained by photographic views, the clouds of spray were projected to a height of not less than 150 ft. If it is assumed, as seems perfectly justifiable, that the horizontal bed joints along the top of blocks *a a*, which were about 5 ft. below low water, were not water-tight joints, the moving of this great mass by the waves of the above description does not appear so extraordinary. The buoyancy of the water would reduce the effective

weight of this block when submerged in the wave to about 730 tons. With a frictional resistance on its bed as high as 75%, a pressure per square foot of surface of about 2 500 lbs. would be sufficient to move the block. The maximum pressure exerted by a wave 42 ft. high would be theoretically about 5 400 lbs. per square foot. It does not appear necessary, therefore, to assume any more mysterious force possessed by such a wave than would be expected by theoretical considerations, to explain its action in this case. In fact, as was afterwards the case, it would not be surprising to find even a larger mass of masonry moved by it.

In 1877 another concrete mass containing 1 500 cu. yds. of cement rubble and weighing about 2 600 tons, substituted for the one just described, was in like manner carried away.

In considering this case a friction of 75% has been assumed for this mass upon its bed. It seems very probable to the author's mind, however, that the impact of the waves upon the water in the bottom seams would greatly assist the other displacing forces.

In Volume CVIII of the *Proceedings* of the Institution of Civil Engineers, there is a very interesting description of the lighthouses built at Bishop's Rock, Scilly Islands. The first, a skeleton iron lighthouse was entirely swept away February 5th, 1850. This was replaced by a masonry lighthouse in 1858. In a brief time the great effects of the sea were noted. During a severe storm a fog-bell weighing 5 cwt. was torn from its bracket on the lantern gallery, 100 ft. above high water.

"When a hurricane of this type was raging, the tower vibrated violently; articles were shaken from the shelves in the rooms and the prisms of the dioptic apparatus fractured. Later on it was discovered that some of the external blocks of granite situated a few feet above high water had been split by the excessive strain imposed on the building.

"The tower was then strengthened from top to bottom by bolting heavy iron ties to the internal surface of the walls and connecting them through the floors. Nevertheless, after a violent storm in 1881, there was again evidence that the heavy strains of the sea had caused further damage. In certain places pieces of granite weighing ½ cwt. were split from the face of the exterior blocks a few feet above high-water level."

It was therefore resolved to strengthen and improve the tower. As it was apparently on the verge of destruction by the storms to which it

had been subjected, it will be interesting to apply the preceding theoretical views to it. Sir James N. Douglas says:

"After the completion of the second work, they had more detailed information through the light-keepers as to the exact movement of those heavy seas. The primary wave flowed freely over the rock at a height of 50 ft. above its summit. There was very little break in the wave except on the tower itself; and there a rather lighter wave arose and reached the cavetto of the lantern gallery (100 ft. above high water), where a third and still lighter wave was produced of heavy spray, which struck the lantern and rising far above it, was driven a long way to leeward, sometimes nearly $\frac{1}{3}$ mile during a heavy storm. He had visited many parts of the world, east and west, but had never seen heavier seas than he had witnessed at Bishop's Rock, where everything appeared favorable to their development."

This tower was 36 ft. in diameter at the high-water line, and for 50 ft. above high water had an exposed wave surface of 1 320 sq. ft., and above the 50 ft. an exposed wind surface of about 1 275 sq. ft. (dimensions scaled from drawings). The cubic contents of masonry was about 38 000 cu. ft.; the weight of the tower and contents was estimated at 6 500 000 lbs., equal to an insistent pressure of about 6 400 lbs. per square foot on the base.

A wave which rose 50 ft. above the rock, which was about high water, would measure at least 66$\frac{2}{3}$ ft. from crest to trough. Such a wave reflected from a flat vertical surface would exert a pressure due to the mean of a water column 133$\frac{1}{3}$ ft. high, but 16$\frac{2}{3}$ ft. of this would be below the base of tower, so only 116$\frac{2}{3}$ ft. will be taken.

For a circular tower, there are theoretical grounds for believing that the pressure will be only one-third of that upon a continuous wall. Then there will be a mean pressure of $116\frac{2}{3} \times 64.3 \div 3 \times 2 = 1\,249$ lbs. per square foot of exposed surface; $1\,249 \times 1\,320$ sq. ft. $= 1\,648\,680$ lbs., which gives an overturning movement of about $1\,648\,680 \times 17 = 28\,027\,560$ foot-pounds.

Forty pounds of wind pressure acting on the upper surface of the tower would increase this moment 2 000 000 foot-pounds, making a total moment of 30 027 560 foot-pounds. The moment of resistance of the base would be $\frac{I}{z} = \frac{\pi \times 18^3}{4} = 4\,580$.

$$\frac{30\,027\,560}{4\,580} = \pm\, 6\,556 \text{ lbs.}$$

causing a reduction of the pressure on the base at the windward side

from 6 400 lbs. to a tension of 156 lbs., and an increase on the leeward side from 6 400 to 12 956 lbs.

No masonry structure could be expected to stand such conditions of strain for a long time.

If, then, it is possible to explain these extreme cases of sea force upon well-recognized mechanical principles, it is safe to accept these same principles as sufficient for estimating the forces which sea structures will have to encounter. In estimating the forces to be resisted by a sea structure, the greatest waves which will possibly impinge against the structure when built must be determined. These may be entirely different from the off-shore waves. It will be necessary to study all the conditions of the location to determine the probable maximum waves which may have to be encountered, if the maximum waves at that point are not already known.

The off-shore waves running into shallower water or converging into narrower limits by the form of the coast or bottom will impart their energy to smaller masses of water, producing waves exceeding those originating them. Or on the contrary, the character of the bottom or foreshore and depths of water may be such as to cause these off-shore waves to break and lose their energy before reaching the structure.

It may be well to quote further from Mr. Thomas Stevenson :

"The determination of the stability of a practically monolithic mass, such as the Eddystone or Bell Rock lighthouses, though difficult enough, is, however, of a simpler nature than that of the disconnected materials of a harbor work. In the masonry of lighthouses the sea is excluded from the joints of the stones, but in many harbor works, the jet of water enters freely into the interior of the masonry and introduces such complexity into the question as to render it impossible, at least in the present imperfect state of our information, to give any rules for directing the engineer. I can therefore simply point out the nature of the different forces which enter into the question of the stability of such loosely built structures, so as to show in what direction the sea attacks the works.

"The impact of the waves against the outside of a sea wall or pier gives rise to four distinct forces, viz.: First, the direct horizontal force which tends to shake loose or drive in the blocks of which the masonry consists; second, the vertical force acting upwards on any projecting stone or protuberance, as well as against the lying beds of the stones; third, the vertical force acting downwards, which results either from the wave breaking upon the toe of the talus wall or from its passing over the parapet and falling upon the pitching behind, so

as to plough it up ; fourth, the back-draught which tends by reaction from the wall to remove the soft bottom, and in this way to undermine the lower courses of the work "

Again he says :

"Within the masonry, as well as without, the waves exert forces in the following different ways: First, by propulsion of vibrations produced by the shock of the waves on the outer or sea wall through the body of the pier to the inner or quay wall. Second, by the direct communication of the impulses through the particles of the fluid occupying the interstices of the hearting so as to act against the back joints of the face wall of the quay. Third, by the sudden condensations and expansions of the air in the hearting so as to loosen and at last to blow out the face stone of the quay, combined with, fourth, the hydrostatic pressure of the water which is forced through the sea wall and from want of free exit is retained and acts as a head at the back of the quay and which, however small in quantity, will act as in a Bramah press upon all surfaces exposed to its pressure, however great those surfaces may be. The three last causes are probably the most efficient agents in the work of destruction."

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Vol. XXII. MAY, 1896. No. 5.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publication.

CONTENTS.

SOCIETY AFFAIRS.

PAPERS.

ILLUSTRATIONS.

The price of publications is as follows: Proceedings, $6 per annum; Transactions, $10 per annum. Postage will be added when they are sent to foreign countries.

American Society of Civil Engineers.

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Term expires January, 1898:
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ON UNITS OF MEASUREMENT:—George M. Bond, William M. Black, R. E. McMath, Charles B. Dudley, Alexander C. Humphreys.

The rooms of the Society are open from 9 to 17 o'clock each business day, except Saturday (when they are closed at 15 o'clock), and at other times on application to the Janitor.

HOUSE OF THE SOCIETY—127 EAST TWENTY-THIRD STREET, NEW YORK.

Vol. XXII. MAY, 1896. No. 5.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS.

CONTENTS:

MINUTES OF MEETINGS.

OF THE SOCIETY.

May 6th, 1896.—The meeting was called to order at 20.15 o'clock, President Thomas Curtis Clarke in the chair; Charles Warren Hunt, Secretary, and present, also, 71 members and 17 visitors.

The minutes of the meetings of April 1st and 15th, 1896, were adopted as printed in *Proceedings* for April, 1896.

A paper by Arthur L. Adams, M. Am. Soc. C. E., entitled "The Astoria City Water-Works" was presented in abstract by the Secretary and discussed by Rudolph Hering, M. Am. Soc. C. E.

Ballots were canvassed and the following candidates were declared elected:

As Members.

Gillmor Brown, Wheeling, W. Va.
James Leaman Brownlee, New Orleans, La.
William Joseph Hardee, New Orleans, La.
Hiram Allen Miller, Clinton, Mass.
William Thomas Pierce, Boston, Mass.
Arthur Leslie Plimpton, Boston, Mass.
Morris Robeson Sherrerd, Newark, N. J.
Archer Cochran Stites, Chicago, Ill.

As Associate Members.

Eduardo Justo Chibas, Colon, Republic of Colombia.
Charles Herbert Deans, New York City.
Xanthus Henry Goodnough, Boston, Mass.
John Fillmore Hayford, Ithaca, N. Y.
Stephen Wistropp Stacpoole, Tlalmanalco, Chalco, Mexico.
John Clark Spencer, Clinton, Iowa.
John George Tait, New York City.

The Secretary announced the election by the Board of Direction on May 5th of the following candidates:

As Associate.

Louis Baldwin Harrison, New York City.

As Juniors.

Adolph Black, New York City.
Charles Perkins Cogswell, Jr., New Haven, Conn.
Rutger Bleecker Green, New York City.
Frank Gordon Ormsby, Easton, Pa.
Arthur Dickson Prince, New York City.
Francis Xavier Aloysius Purcell, New York City.
Ernest Woodbury Wiggin, New Haven, Conn.

The Secretary announced the death on February 1st, 1896, of Christopher C. Waite, elected Member March 3d, 1880.

The Secretary made the following announcements:

Twelve designs for the New Society House have been received, eight from members of the Society, and four from architects not connected with it who had been invited to submit plans. The design of Mr. C. L. W. Eidlitz has been selected, and he has been retained by the Board of Direction as architect.

At the regular meeting to be held on June 3d, 1896, William H. Burr, M. Am. Soc. C. E., will describe some experimental pile-driving through new stone-filled cribwork. At the same meeting Charles O.

Brown, M. Am. Soc. C. E., will explain the engineering features of the proposed new building law of New York City.

General arrangements for the 28th Annual Convention to be held in San Francisco, June 29th to July 3d, have been placed in the hands of a special committee of the Board of Direction, consisting of Messrs. Joseph M. Knap, *Chairman;* William Barclay Parsons, George A. Just, Horace See and Charles Warren Hunt. Messrs. George E. Gray, *Chairman;* George H. Mendell, William G. Curtis, James D. Schuyler and William B. Storey, Jr., have been appointed a Local Committee of Arrangements. The party from the East will leave New York on June 22d, and go to San Francisco by way of Chicago, Omaha, Denver and Ogden, and will return by way of Portland and Vancouver over the Canadian Pacific system. Further particulars will be given in a special circular to be issued in a few days.

Adjourned.

May 20th, 1896.—The meeting was called to order at 20.15 o'clock, Past-President William Metcalf in the chair; Charles Warren Hunt, Secretary, and present, also, 66 members and 13 visitors.

A paper entitled "Some General Notes on Ocean Waves and Wave Force," was presented by Theodore Cooper, M. Am. Soc. C. E., and discussed by Messrs. L. L. Buck, Charles Macdonald, Foster Crowell, B. S. Church, William Metcalf and Theodore Cooper. A communication on the subject from Robert Fletcher, Assoc. Am. Soc. C. E., was read in abstract by the Secretary.

Joseph M. Knap, chairman of the Convention Committee of the Board of Direction, announced that owing to delays in securing special rates from the various traffic associations, and on account of the withdrawal by the Canadian Pacific Railway Company of the partial promise of a very low rate made by one of its officers, it had been impossible to make any definite statement as to rates or routes up to the present time, but that a circular would be sent out in a few days. The details of the traveling arrangements had been placed in the hands of Messrs. Raymond and Whitcomb.

The Secretary stated briefly the various trips which had been planned and gave their cost as now figured, which may be reduced if the Trunk Line Association grants a rate for which application has been made.

The Secretary announced the death of Norman James Nichols, elected Member December 5th, 1888; died April 8th, 1896.

The Secretary stated that the discussion on the paper by Arthur L. Adams, M. Am. Soc. C. E., presented May 6th, would be closed June 15th, 1896, and that the discussion on Mr. Cooper's paper would close July 1st, 1896.

Adjourned.

OF THE BOARD OF DIRECTION.

May 5th, 1896.—Fourteen Members present.

The Finance Committee presented a report of the assets available for the building of the New Society House, and of the prospective liabilities on the assumption that the House and its furnishing would cost $100 000.

The Building Committee reported in the matter of the choice of an architect for the New Society House, and on other matters relating to the competitive designs which had been furnished.

Mr. C. L. W. Eidlitz was appointed architect for the New Society House.

The resignation of Geo. F. Swain, M. Am. Soc. C. E., as a member of the Committee on Units of Measurement, was presented and accepted.

Chas. B. Dudley, M. Am. Soc. C. E., and Alexander C. Humphreys, M. Am. Soc. C. E., were appointed members of the Committee on Units of Measurement.

Applications were considered and other routine business transacted.

Adjourned.

ANNOUNCEMENTS.

MEETINGS.

Wednesday, June 3d, 1896, at 20 o'clock, a regular meeting of the Society will be held, at which William H. Burr, M. Am. Soc. C. E., will describe some experimental pile-driving through new stone-filled cribwork.

At the same meeting Charles O. Brown, M. Am. Soc. C. E., will explain the engineering features of the proposed new building laws of New York City. Mr. Brown is a member of the Sub-Committee on Formulas and Calculations of the General Committee engaged in the revision of the building laws, and will describe informally the conclusions which the Sub-Committee has drawn from its study of the subject. The new formulas and methods of calculation will be explained, and some of the defects of the old laws pointed out. The new law gives the proposed formulas for columns, with and without eccentric loading, beams, riveting, wind pressure, footings, deflection of beams, arches, retaining walls, and other structural features of city buildings.

Annual Convention, June 29th-July 3d.—Five papers will be presented at the Annual Convention, all of which are printed in this number of *Proceedings*. They are as follows:

"Flow of Water in Wrought and Cast-Iron Pipes from 28 to 42 Ins. in Diameter." By Isaac W. Smith, M. Am. Soc. C. E.

"A Water Power and Compressed Air Transmission Plant for the North Star Mining Company, Grass Valley, Cal." By Arthur De Wint Foote, M. Am. Soc. C. E.

"The Condition of Steel in Bridge Pins." By A. C. Cunningham, M. Am. Soc. C. E.

"The Construction of a Light Mountain Railroad in the Republic of Colombia." By E. J. Chibas, Assoc. M. Am. Soc. C. E.

"Improving the Entrance to a Bar Harbor by a Single Jetty." By T. W. Symons, M. Am. Soc. C. E.

Correspondence on the above papers is invited from those who cannot be present at the meetings, and may be sent by mail to the Secretary. The papers, with discussion, will be published in *Transactions*.

DISCUSSIONS.

Discussion on the paper by A. L. Adams, M. Am. Soc. C. E., entitled, "The Astoria City Water-Works," which was printed in *Proceedings* for April, 1896, will be closed June 15th, 1896.

Discussion on the paper by Theodore Cooper, M. Am. Soc. C. E., entitled, "Some General Notes on Ocean Waves and Wave Force," which was printed in the same number of *Proceedings*, will be closed July 1st, 1896.

Discussion on the papers presented at the Annual Convention and printed in this number of *Proceedings* will be closed August 15th, 1896.

MEMOIRS OF DECEASED MEMBERS.

ZERAH COLBURN, M. Am. Soc. C. E.*

Died April 26th, 1870.

More than a generation has passed away since the brilliant career of Zerah Colburn closed prematurely in the snow-covered orchard at Belmont, Mass. It is somewhat difficult, after the lapse of six and twenty years to recall with accuracy or consecutiveness the details of his feverishly busy life, and still more difficult to find authentic records, which are more valuable than personal reminiscence. On the other hand, viewed in the perspective given by time, the errors that wrecked his life assume their proper proportions, and have ceased to tarnish the great qualities that made Zerah Colburn one of the famous en-

* Memoir prepared by James Dredge, Esq.

gineers of his period. The curious autobiography of the earlier Zerah Colburn, published in 1833, throws some light upon the status of his family. With two exceptions it was of very ordinary stuff; the paternal grandfather was a needy unsuccessful farmer in New England; his wife a woman of strong intellect and sound judgment, who kept the home together and brought up a family, while he was seeking fortune in Europe by the exhibition of the extraordinary powers of calculation possessed by one of his children, the only member of the family who was fit for better things than the routine of farm labor. This was the first Zerah Colburn, who apparently gained more celebrity in Europe than in his native country. It is remarkable that the wonderful gift he enjoyed brought him so poor a result; in quite early life he became a minister of some dissenting denomination, and we hear no more of his calculating powers. The second Zerah Colburn, the subject of this sketch, was the son of one of the calculating Zerah's brothers, who lived and died unknown. The younger Zerah was born in 1832, shortly after his uncle had become a preacher, and when the honors of his calculating prowess were still thick upon him. Besides the name, Zerah Colburn inherited a vein of genius from his uncle, though of a different nature and tending to a more useful purpose. The farm which was his birthplace was in Saratoga, N. Y. Here his earliest years were passed, almost devoid of education, and filled with monotonous labor. But very soon—probably before he was ten years old—his extraordinary force of character and precocious development had revealed to him that the possibilities of a great future lay before him. Whence came the strong bent towards mechanics is as deep a mystery as the source from which his uncle's mathematical powers were derived, but it forced him onward, first to some local cotton mill, and afterward to the shops of the Concord Railroad, where the then superintendent, Mr. Minot, gave him his first chance, by which he profited so well that he speedily became a person of some importance on the railway.

Colburn must have stayed some years with Mr. Minot, probably three or four, but he left him in order to enter the Tredegar Locomotive Works at Richmond, Va. I believe, indeed, that there was an intermediate stage in his career, though a rather brief one. This was a short stay at some locomotive works in Boston, during which time he so far qualified himself, and so gained the confidence of capitalists, that before he was twenty-one he was a managing partner in the Tredegar Works. That he should have traveled so fast on the road to success was indeed marvelous. He was without education, except what was self-acquired; he had no influence and only self-made friends, and the lack of steadfastness in purpose, which proved in the end his ruin, was already making itself felt. But he possessed unlimited belief in himself, his power of absorbing and retaining knowledge ap-

peared unbounded, he possessed an apparently inexhaustible store of physical strength, and he owned these qualities to such a degree that almost to the close of his life they more than counterbalanced the disadvantages of circumstance and character.

With the termination of his connection with the Richmond Locomotive Works, Colburn's practical career came to an end, and when he was little more than two and twenty he had entered on the new path which he followed more or less fitfully to the end of his life. This was the career of technical journalism. In 1851 the engineering profession had no press worthy of the name, and Colburn realized that therein there was a great future for him. He had already made successful experiments in this direction; when he was only fourteen or fifteen years of age he had written and published (finding the means somehow, as he always contrived to do) a monthly magazine devoted to engineering subjects; it was but a small, poor thing, but nevertheless it contained the germs of the marvelous engineering press of today. This publication, under the name of *Monthly Mechanical Tracts*, had but a short existence, and had become extinct before he left Mr. Minot, about 1849. Afterward he contributed to the *American Railway Times* of Boston, and later to the *American Railway Journal*, of which he was for some time assistant editor. But these efforts were only experimental, and in 1854 he commenced an engineering journal on his own account under the title of the *Railroad Advocate*. This, in the course of a short time, he developed into a relatively great success, so much was it impressed with the genius of its powerful editor. But it was impossible for Colburn to work steadily for any length of time; he had made his mark as an original thinker, an able engineer and a powerful journalist, but, having achieved these things, he tired of his enterprise, and sold it to Alexander L. Holley, who had not then risen into fame, and who had the fancy of owning and editing an engineering paper. The venture was not profitable, except for Colburn. and the journal dragged on a languishing existence for about 18 months, during which Colburn was a frequent contributor, at the same time attempting the utterly uncongenial and unsuccessful attempt to establish himself as a commercial engineer.

The summer of 1857 saw him in Europe, and on his return he bought back an interest in the *Railroad Advocate*, changed the name to the *Railway Engineer*, and conducted it with Holley for a year longer, when it died. He had returned to Europe in the fall of 1857 on a special mission, the work and pleasures of which he shared with Holley; at this time Colburn was not twenty-six years of age, Holley being a little his senior. These two brilliant young men visited Europe at the request of several leading American railroads with the purpose of reporting on English railway practice. The visit proved to be a turning point in Colburn's life; it terminated—with a few

fitful exceptions—his residence in the United States, and made England his future home. Returning to America in the fall of 1857, he and Holley, in an incredibly short time, produced what was for a long time a standard book on European railways. In 1858 Colburn was back in London, and during the summer of that year he became editor of *The Engineer*, of London, a journal that had been started and feebly conducted for a few years. Colburn's energy, skill and brilliant qualities soon impressed themselves on the paper and raised it into a strong position, but he tired of the work, and, returning to America in 1860, started a paper in Philadelphia on his own account. and bearing the same title, *The Engineer*. After five months this was abandoned, and the next year he returned to London, and was gladly received again as editor of *The Engineer*, This position he retained longer than any other during his life, for he did not finally quit his active work as its editor till 1864.

Then followed a period of general engineering practice and the preparation for the final venture of his life, the establishment of *Engineering*. The first number of this journal appeared in the beginning of January, 1866, and during the next sixteen months almost every page bore the stamp of his energy and genius. With the opening of the Paris International Exposition of 1867 he once more, and for the last time, fell away from the path of usefulness and work, and a record of the next four years would be but a melancholy story, relieved by occasional flashes of light, sufficiently brilliant, however, to prove that his great powers remained unaffected to the last. The facts may be stated now after so many years. Colburn's besetting weakness, or rather his incurable disease, was one before which many full of talent, like De Quincy and Edgar Allan Poe, had fallen before his time.

During the brief years into which Colburn's active career must be compressed, he achieved a high and lasting reputation, and it may in all justice be claimed for him that he was the creator of engineering journalism. It is believed that the following list of his life's literary work is a fairly complete one; it is compiled to a large extent from his own memoranda:

1847.—Wrote *Monthly Mechanical Tracts*, published at Lowell.

1848.—Wrote *The Locomotive Engine*, published in Boston.

1851-53.—Was contributor to the Boston *American Railway Times*.

1852.—Was contributor to the *Carpet Bag*.

1853.—Became assistant editor of the *American Railroad Journal*.

1854.—Started, as editor and proprietor, the *Railroad Advocate*.

1856.—Sold the *Railroad Advocate* to A. L. Holley and attempted several things, contributing at the same time to the *Railroad Advocate*.

1857.—Visited Europe, and on his return bought an interest in the *Railroad Advocate*.

1857.—Second visit to Europe; this time with Holley to report on European railway practice.

1858.—Published, with Holley, "The Permanent Way and Coal-Burning Locomotive Boilers of European Railways."

1858.—Wrote the American section of D. K. Clark's book on "The Recent Practice in the Locomotive Engine."

1858.—Became editor of *The Engineer*, London.

1860.—Published an essay on "Steam Boiler Explosions" (John Weale & Sons).

1860.—Started, as editor and proprietor, *The Engineer*, Philadelphia.

1861.—Became editor of *The Engineer*, London, for the second time.

1863.—Wrote "An Enquiry into the Nature of Heat," published by Spon.

1863.—Wrote paper for the Institution of Civil Engineers "On American Iron Bridges."

1863.—Wrote paper for the London Society of Engineers "On the Relation Between the Safe Load and the Ultimate Strength of Iron."

1864.—Published "Gas Works of London" (Spon).

1864.—Wrote a part of "Locomotive Engineering." (This was published by Collins & Co., of Glasgow, but was not finished by Colburn.)

1864.—Resigned the editorship of *The Engineer*.

1864.—Read a paper, "A Description of the Harrison Steam Boiler," before the Institution of Mechanical Engineers.

1865.—During this year Colburn was a contributor to *The Engineer*, and he wrote and read the following papers: "On Certain Methods of Treating Cast Iron in the Foundry" (Society of Engineers); "On the Ginning of Cotton," and "On the Manufacture of Encaustic Tiles, etc., by Machinery" (Society of Arts).

1866.—Founded London *Engineering*.

1869.—Read papers "On American Locomotives and Rolling Stock" before the Institution of Civil Engineers; and a second, "On Anglo-French Communications," before the Society of Arts.

Zerah Colburn was a member of several institutions, among others of the American Society of Civil Engineers, of the London Institution of Civil Engineers, of the Institution of Mechanical Engineers, and of the Iron and Steel Institute; he was also a President of the London Society of Engineers. He was elected a Member of the American Society of Civil Engineers on January 5th, 1855.

HENRY FREDERICK RUDLOFF,* M. Am. Soc. C. E.

Died June 1st, 1895.

Henry Frederick Rudloff died at Caracas, Venezuela, June 1st, 1895. At the time of his death he was Chief Engineer of the Puerto Cabello & Araure Railway, and was also in the service of the Venezuelan government in charge of various minor engineering works.

He was born in Prussia, September 12th, 1846, graduated from the Gewerbe Institute in Berlin in 1866, and from that time until 1878 was engaged upon various public works in different parts of Europe, his father being a prominent constructor. He came to America in 1878, and during the next three years had several engineering engagements, among them office duties with Clarke, Reeves & Company, of Phoenixville, Pa.; with Gen. McClellan on a projected underground railway, and with the West Shore Railroad. In 1881 he entered the service of the government of Venezuela, and became division engineer on the La Guayra & Caracas Railroad, then in progress of construction, having charge of tunnels and bridges upon that road. In 1883 he was appointed Government Engineer at Caracas and designed a number of works, including a notable stone arch and an iron viaduct in Caracas. In 1884 he became the engineer of an American company, and under his direction the works of improvement of the harbor at Puerto Cabello were carried out. He was also the engineer of the Caracas & Antimano Railroad, and continued to the time of his death in government service, in addition to his engagement with the American company.

Mr. Rudloff was a man of exceptional ability in the direction of public works in Spanish-American countries. He had command of several languages, and was able to apply the results of varied experience to the special requirements of construction in those countries. He was entrusted, both by the Venezuelan government and by the representatives of foreign capital in that country, with the design and construction of engineering work of considerable magnitude, and always with satisfactory results. His death was sudden and unexpected, coming at a time of promise of much more extended possibilities. He leaves a widow and one son, who reside at Caracas, Venezuela.

He was elected a Member of the American Society of Civil Engineers January 6th, 1886.

* Memoir prepared by John Bogart, M. Am. Soc. C. E.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

			Date of Membership.
ADGATE, GEORGE	Rock Island, Ill.		April 1, 1896
FISK, WALTER LESLIE	P. O. Drawer 50, Portland, Ore.		April 1, 1896
JANNEY, WILLIAM DEAN	Ceredo, Wayne County, West Va.	Assoc. M. M.	May 6, 1891 Apr. 1, 1896
McCURDY, JOHN EGBERT	Apartado 36, Chihuahua, Mexico		April 1, 1896
PIERCE, WILLIAM THOMAS	13 Exchange St., Boston, Mass.		May 6, 1896
REED, DAVID ABELL	City Hall, Duluth, Minn.		March 4, 1896
SABIN, ALPHEUS TIMOTHY	126 7th St., Louisville, Ky.		April 1, 1896
SHERRERD, MORRIS ROBESON	128 Halsey St., Newark, N. J.	Assoc. M. M.	May 3, 1893 May 6, 1896

ASSOCIATE MEMBERS.

CHIBAS, EDUARDO JUSTO	127 East 23d St., N. Y. City.	Jun. Assoc. M.	Mar. 31, 1891 May 6, 1896
FORT, EDWIN JOHN	475 Evergreen Ave., Brooklyn, N. Y.		April 1, 1896
HUTCHINSON, CARY TALCOTT	253 Broadway, N. Y. City.		March 4, 1896
STOCKETT, ALFRED WALTON	P. O. Box 1906, Johannesburg, South African Republic		Jan. 1, 1896

ASSOCIATE.

KNOWLTON, THEO. ELY	838 Niagara St., Buffalo, N. Y.	March 31, 1896

JUNIORS.

BOYD, JAMES CHURCHILL	1430 St. Charles St., Denver, Colo.	Sept. 3, 1895
BROWN, THANE ROSS	(Care Wisconsin Bridge Co.), No. Milwaukee, Wis.	March 31, 1896
CLARKE, JR., THOMAS CURTIS	28 West 34th St., N. Y. City	March 3, 1896
COGSWELL, JR., CHARLES PERKINS	(Care N. Y., N. H. and H. R.R.), New Haven, Conn.	May 5, 1896
WIGGIN, ERNEST WOODBURY	(Care N. Y., N. H. and H. R.R.), New Haven, Conn.	May 5, 1896

CHANGES AND CORRECTIONS.

MEMBERS.

Appleton, Thomas................Eng. of Bridges and Water Supply, Gt. Northern Ry., St. Paul, Minn.
Bassel, Robert..................Weender Chaussée 13, Göttingen, Germany.
Beahan, Willard.................(Care College of Engineering, Cornell Univ.), Ithaca, N. Y.
Bensel, John A..................5 Bowling Green, N. Y. City.
Bogue, Virgil G.................1731 Monadnock Block, Chicago, Ill.
Booth, William H................Piccadilly Mansions, 17 Shaftesbury Ave., W. London, England.
Covode, James Henry.............57 East 59th St., N. Y. City.
Cunningham, J. H................2 Ravelston Place, Edinburgh, Scotland.
Eggleston, T. C.................Chula, Amelia Co., Va.
Fairleigh, J. A.................Sta. A, Niagara Falls, N. Y.
Force, C. G.....................Chf. Asst. Eng., Dep't Public Works, Cleveland, Ohio.
Gifford, George E...............501 5th Ave., N. Y. City.
Goldmark, Henry.................1731 Monadnock Block, Chicago, Ill.
Graham, Charles H...............61 Elm St., New Rochelle, N. Y.
Haven, William A................121 School St., Buffalo, N. Y.
Hunt, Randell...................530 California St., San Francisco, Cal.
Keith, George T.................Olean, N. Y.
Kelley, Howard G................Chf. Eng. St. Louis & So. Western Ry. System, Texarkana, Texas.
Lynch, Michael L................Oklahoma City, O. T.
Marstrand, Otto J...............9 West 107th St., N. Y. City.
McLain, Louis R.................Fitzgerald, Florida.
Nearing, Frank..................P. O. Box 216, Jamestown, N. Y.
Perkins, Charles P..............Wayne, Pa.
Raasloff, H. E. de..............38 Park Row, Room 61, N. Y. City.
Rogers, Fairman.................(Care Dick Bros. & Co.) 134 S. 4th St., Philadelphia, Pa.
Shaw, S. F......................Zacapa, Guatemala, C. A.

ASSOCIATE MEMBERS.

Body, John B....................Apartado 58, Vera Cruz, Mexico.
Folwell, Amory P................6331 Hancock St., Germantown, Phila., Pa.
Healey, John F..................Supt. Mt. Clare Coal Co., Mt. Clare, W. Va.
Howard, Charles P...............Sunflower, Raleigh Co., W. Va.
Pennypacker, L. P...............Inspecting Eng. Govt. Guatemala, Guatemala Northern Railway, Zacapa, Guatemala, C. A.
Phillips, Hiram.................306 Oriel Bldg., St. Louis, Mo.
Stanford, Homer R...............Supt. of shops Pittsburgh Bridge Co., Box 45, Station B, Pittsburgh, Pa.

JUNIORS.

Baum, George..........Engr. Clonbrock Boiler Co., Brooklyn, N. Y.
Bell, James G..........(Care A. T. & S. F. R. R.), Guthrie, O. T.
Boecklin, Werner..........Chf. Engr's Office, Penna. Co., Pittsburgh, Pa,
Evans, Peter Platter..........7 Water St., Boston, Mass.
Ford, William H..........21 High St., Medford, Mass.
Gormly, W. B..........11 13th St., Troy, N. Y.
Kinsey, Frank W..........22 State St., N. Y. City.
Pegram, W. M..........Cons. Traction Co., 202 Times Bldg., Pittsburgh, Pa.
Sirrine, Joseph E..........Supt. Const. Abbeville Cotton Mills, Abbeville, S. C.
Waddell, Montgomery..........72 Trinity Place, N. Y. City.

FELLOW.

Cheney, Nathaniel..........Lock Box 134, Orange, Mass.

DEATH.

Nichols, Norman James..........Elected Member December 5th, 1888; died April 8th, 1896.

BOOK NOTICES.

THE SEWERAGE ENGINEER'S NOTE-BOOK.

Being Standard Notes on Sewer Formulæ and Sewerage Calculations. By Albert Wollheim, Assoc. M. Inst. C. E., pp. 140, 4¼ x 7 ins., cloth. St. Bride's Press, London, 1896.

This work has been developed by the author from notes and data collected in the course of his practice as a sewerage engineer, and is now published by him as a book of reference. Its five parts are given to general formulas, standard sections of sewers, sewer discharge formulas, diagrams of sewer discharge and velocity, and the relation between rainfall and sewer discharge. An appendix gives a number of formulas and examples showing the application of the tables, for pipes, circular, standard and new egg-shape sewers; tables of quantity of brickwork for circular and egg-shape sewers; excavation in trenches; sewage flow; rainfall on drainage areas; rate of rainfall and Kutter's coefficient for different conditions. Blank leaves scattered through the book give opportunity for reader's memoranda.

WATER SUPPLY.—(Considered principally from a Sanitary Standpoint.)

By William P. Mason. Cloth, 6 x 10 ins., pp. 504. John Wiley & Sons, New York. Chapman & Hall, London, 1896.

This book is, to some extent, one of compilation, much of the information, especially that in the tables, having been drawn from many sources; but the author, while giving due credit, has made this so completely his own and has incorporated it with so much new material that the result seems like an entirely original work. The treatment of water supply, as the sub-title indicates, is not taken in a general sense but in a limited one as viewed from a sanitary standpoint. Drinking water and the diseases produced by impurities, the artificial and natural purification of water, rain, ice and snow, stored and ground water and chemical and bacteriological examination are treated in respective chapters. There are also chapters given to per capita supply and rates charged in American and foreign cities and the action of water upon metals.

An appendix gives analyses of city water supplies of twenty American cities and statistics showing deaths from typhoid fever per 100 000 inhabitants in twenty-four American and twenty-nine foreign cities.

FIELD-BOOK FOR RAILROAD ENGINEERS.

Circular and Parabolic Curves, Turnouts, Vertical Curves, Leveling, Computing Earth Work. Transition Curves on New Lines and Applied to Existing Lines, together with Tables of Radii, Ordinates, Long Chords, Logarithms, Logarithmic and Natural Sines, Tangents, etc., and a Metric Curve Table. By John B. Henck, A. M. Second revised edition, 4 x 6½ ins., mor., pp. 312. D. Appleton & Co., New York, 1896.

Henck's Field-Book is so well known that it is unnecessary to give a statement of the general contents of this edition. The changes made in it, as compared with the earlier editions, are chiefly in the addition of a chapter on the transition curve, in which the methods of analysis are stated to be entirely new. The old table of radii, ordinates, tangent deflections and ordinates for curving rails has been enlarged materially, and some changes have been made in other tables. Methods are also given for readily extending a short metric curve table which forms part of the book.

ANLEITUNG ZUR AUSFÜHRUNG GRAPHISCHER KONSTRUKTIONEN IM MASCHINENBAU.

By Dr. Hederich. Part 1, Gears and Shafts. Jena, Hermann Costenoble. Paper, 9½ x 6½ ins., pp. 43, 9 tables.

The first part of the work bearing the above title contains nine sections on the principles of graphical calculations, and their application to the solution of problems relating to gearing and shafts. The author calls particular attention to his method of determining the section of minimum size to resist combined torsion and bending, and to a new method of calculating shafts.

ADDITIONS TO

LIBRARY AND MUSEUM.

From American Institute of Architects, Providence, R. I.:
Proceedings of the Twenty-ninth Annual Convention, October 15th to 17th, 1895.

From American Institute of Mining Engineers, New York:
Notes on Conveying-Belts and their Use.
Proceedings of the Seventieth Meeting, February, 1896
Some Fuel Problems.
Standard Physical Tests for the Product of the Blast Furnace, and their Value.
The Essay by Prospectors of Auriferous Ores and Gravels by Means of Amalgamation and the Blowpipe.
The Effect of Additions of Titaniferous to Phosphoric Iron-Ores in the Blast Furnace.
The Effect of Expansion on Shrinkage and Contraction in Iron Castings.
The Effect of Washing with Water upon the Silver Chloride in Roasted Ore.
The Embreeville Estate, Tennessee.
The Hydraulic Elevator at the Chestatee Mine, Georgia.
The Mobility of Molecules of Cast Iron.
The Volatilization of Silver in Chlorodizing-Roasting.

From D. Appleton & Co., New York:
A Treatise on Surveying, comprising the Theory and the Practice, by William M. Gillespie.
Field-Book for Railroad Engineers, by John B. Henck.

From Board of Railroad Commissioners of Iowa, Des Moines, Iowa:
Eighteenth Annual Report for the year ending June 30th, 1895.
Map of Iowa prepared and printed for the Railroad Commissioners to accompany their Report.

From Board of Railroad Commissioners of New York, Albany, N. Y.:
Thirteenth Annual Report for 1895. Two volumes.

From Board of Trustees of the Sanitary District of Chicago:
Proceedings, March 18th, 25th; April 1st, 8th.

From Boston Public Library, Boston, Mass.:
Annual Report of the Trustees for 1895.

From California Academy of Science, San Francisco, Cal.:
Proceedings, Volume V, Part 2.

From Canadian Society of Civil Engineers, Montreal, Canada.
Report of Proceedings of Annual Meeting, January 14th and 15th, 1896.
Charter, By-Laws and List of Members, 1896.

From Theodore Cooper, New York:
General Specifications for Steel Railroad Bridges and Viaducts.

From J. J. R. Croes, New York:
The Palisades of the Hudson.

From Mordecai T. Endicott, Washington, D.C.
Hearings on House Bill 35 (on the Nicaragua Canal) before the Committee on Interstate and Foreign Commerce, House of Representatives.

From Engineers' Society of Western New York, Buffalo, N. Y.:
Papers, Vol. I, Nos. 1, 2, 4, 5 and 6.

From Leon Francq, Paris, France:
Traction Mécanique des Tramways.
Moteurs à Vapeur sans Feu ou à Eau Chaude.

From Alphonse Fteley, New York:
Report on the World's Columbian Exposition in Chicago, 1893. (In Russian.)

From Charles W. Gay, Lynn, Mass.:
Twenty-seventh Annual Report of the City Engineer of the City of Lynn, for the year ending December 31st, 1895.

From B. M. Harrod, New Orleans, La.:
Specifications for the Construction of a System of Drainage for the City of New Orleans, La.

From Institution of Civil Engineers, London, England:
List of Members, 1st April, 1896.
Minutes of Proceedings, Volume cxxiii.

From Institute of Marine Engineers, Stratford, Eng.:
Transactions, Volume V. 1893-94.

From John Kennedy, Montreal, Canada:
Annual Reports of the Harbour Commissioners of Montreal for the year 1895. (2 copies.)

From J. P. Lesley, Philadelphia, Pa.:
Summary Final Report Pennsylvania Geological Survey. Vol. 3. Parts 1 and 2.
Index Final Summary Report, 1895.
Atlas to accompany Report F. Z. Geological Survey of Pennsylvania.

From Charles Mayne, Shaughai, China:
Report of the Municipal Council, Shanghai, for the year ended, 31st December, 1895.

From Meteorological Observatory, Central Park, N. Y.:
Annual Tables, Daily and Hourly, for the year 1895.

From Patent Office, London, England:
Abridgments of Specifications for Patents for Inventions, 1884-88; Electricity, Measuring and Testing; Tea, Coffee, Cocoa and Like Beverages; Sugar; Aeronautics; Starch, Gum, Size, Glue and other Stiffening and Adhesive Materials; Life-Saving and Swimming and Bathing Appliances; Hats and other Head Coverings; Manufacture of Fuel; Fish and Fishing; Chains, Chain Cables, Shackles and Swivels.

From Public Works Department, Madras, India:
Administration Report of the Irrigation Branch in the Madras Presidency for the years 1894-95.

From Amerigo Raddi, Florence, Italy:
Le Nuove Proposto per Addurre in Firenze Nuove Acque Potabili.

From Royal Institute of Engineers, Hague, Holland:
Notulen der Vergaderingen. Tweede en Derde Afleveringen.
Verhandelingen, Vertalingen, etc. Tweede en Derde Afleveringen.

From Royal Society of Canada, Ottawa, Canada:
Note on Secondary Undulations recorded by Self-Registering Tide Gauges and on Exceptional Tides in Relation to Wind and Barometer.

From Pemberton Smith, Buffalo, N. Y.:
A Series of Tests made by the P. H. Griffin Machine Works of Buffalo, N. Y., on November 8th, 1895, with Special Qualities of Wheels made by the New York Car Wheel Works.

From Society of Civil Engineers of France, Paris, France:
Annuaire de 1896.

From E. Herbert Stone, Allahabad, India:
Tables of Quantities for Small Span Bridges and Culverts adapted to the Conditions of Railways in India on the 5 ft. 6 in. and Meter Gauge.

From U. S. Department of Agriculture, Division of Forestry:
Economic Designing of Timber Trestle Bridges.
Southern Pine—Mechanical and Physical Properties.

From U. S. Department of the Interior:
Thirty-six maps of the U. S. Geological Survey.

From U. S. Treasury Department:
Report of Transportation Business in the United States at the Eleventh Census, 1890, Part I. Transportation by Land.
Report on Vital and Social Statistics in the United States at the Eleventh Census, 1890, Part III. Statistics of Deaths.
The Foreign Commerce and Navigation of the United States for the year ending June 30th, 1895.
Immigration and Passenger Movement at Ports of the United States during the year ending June 30th, 1895.

From U. S. War Department, Chief of Engineers:
Annual Report of the Chief of Engineers, 1895, seven parts.

From University of Wisconsin, Madison, Wis.:
Electrical Engineering in Modern Central Stations.

From John Wiley & Sons, New York:
Water Supply (Considered Principally from a Sanitary Standpoint).

From Albert Wollheim, London, England:
The Sewerage Engineer's Note-Book.

From E. D. Worcester, New York:
Twenty-sixth Annual Report of the Lake Shore and Michigan Southern Railway Company, 1895.
Report of the Board of Directors of the Michigan Central Railroad Company for the year ending December 31st, 1895.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

PAPERS.

CONTENTS:

FLOW OF WATER IN WROUGHT AND CAST-IRON PIPES FROM 28 TO 42 INS. IN DIAMETER.

By ISAAC W. SMITH, M. Am. Soc. C. E.

TO BE PRESENTED AT THE ANNUAL CONVENTION, 1896.

The water supply of the city of Portland, Ore., is from the Bull Run River, which heads in a lake fed by springs 3 500 ft. above sea level and 10 miles from Mount Hood in the Cascade Mountains. It runs with an average fall of 100 ft. to the mile over a bed of rocks and boulders between high walls of rock and hard pan into the Sandy River, a few miles above the place of its discharge into the Columbia. The water-shed of 220 sq. miles, now a government reservation, is mountainous, covered with timber, and unfit for settlement or occupation, and the main stream and its tributaries carry down but little sand or gravel, and not enough clay or alluvial soil to color the water

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

during the highest floods. The temperature of the water, which averages about 38° Fahr. in winter, 45° in the spring and fall, and 55° in summer, does not change in passing through 30 miles of pipes. The minimum discharge is about 70 000 000 galls. in 24 hours, of which a third is now taken for the city water supply.

The water is diverted from the stream at the head of a rapid by means of a canal 400 ft. in length, terminating in a chamber from which it is discharged through a funnel 9 ft. in length and with a diameter tapering from 5 to 3½ ft., the latter being the diameter of the discharge pipe. A 42-in. gate is placed at a distance of 30 ft. from the head for the purpose of regulating or shutting off the water supply to the city. The head lost from the water chamber to a point below

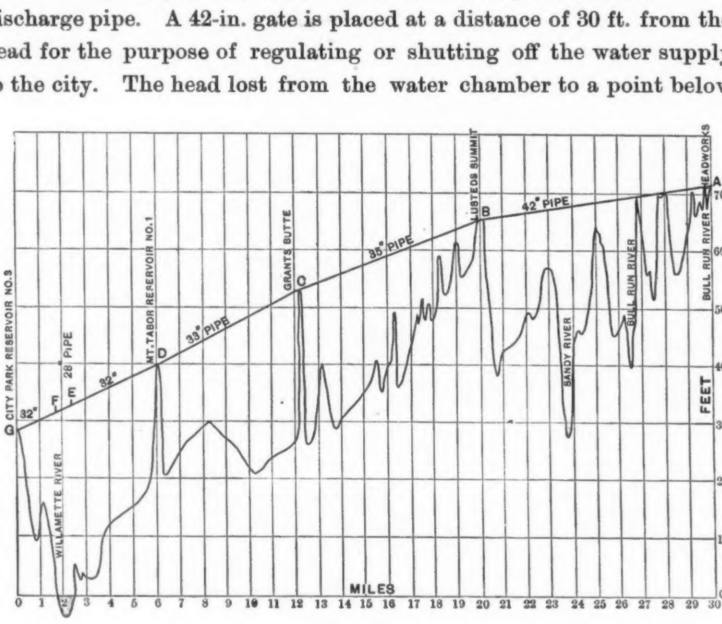

FIG. 1.

the gate is 6 ins. From the head to the foot of the canal there is a fall in the river of 16 ft. at low water, and as the canal walls are but 3 ft. in height, the flood waters are wasted over the top of the wall and there is but little variation in the level of the water in the water chamber.

The water is conducted to the city through a riveted steel and a cast-iron pipe, the one 24 miles and the other 6 miles in length. The steel pipe extends from the source to a reservoir on the east side of the Willamette River; the cast-iron pipe extends thence to a reservoir on the west side, passing under the river by means of a submerged pipe 2 006 ft. in length, as shown in Fig. 1.

At each reservoir the water ascends vertically into the gate chamber and flows through screens over a weir 6.97 ft. long with two end contractions, which differs only from the regulation weir in having a circular channel of approach. On the outside of the channel there is a a float supporting a gauge, which shows the height H of the water, and the corresponding discharge Q, calculated by the formula,

$$Q = 3.33\ (\text{length} - \frac{H}{5}) \times H^{\frac{3}{2}}$$

This float is adjusted by means of a hook gauge on the outside of the circular channel, but it is found that the height is 0.02 ft. greater on the inside.

The capacity of each reservoir was carefully measured, and the depth of the water in feet and the surface level for each 1 000 000 galls. were marked on a rod attached to the gate house and resting on the bottom.

On March 28th, 1895, 2 995 000 galls. by reservoir measurement was turned into Reservoir No. 1 in 3.7 hours, and 617 000 galls. by weir measurement into other reservoirs, making 3 612 000 galls. in 3.7 hours, or 23 410 000 galls. in 24 hours.

The flow by weir was 23 750 000 galls., or 340 000 galls. more than the reservoir and weir measurements combined. On January 21st, 1896, all of the water was turned out of Reservoir No. 1, and the full flow from Bull Run then turned in, and as the surface of the water rose to each million mark on the rod from 1 to 10, the time was noted and found to be 1 hour and 1 minute in seven instances, and 1 hour and 2 minutes in three, giving a flow of 10 000 000 galls. in 10 hours and 13 minutes, or 23 491 000 galls. in 24 hours. During the whole time the height of water above the weir stood steadily at 1.37 ft. on the outside of the circular approach and 1.39 ft. on the inside, giving a flow in 24 hours of 23 100 000 galls. for the first, and 23 592 000 galls. for the second, which differs only 100 000 galls. from the flow by reservoir measurement.

By tests made carefully at different times, it was ascertained that there was no appreciable leakage, either from the reservoir or from the supply main from Bull Run. As the weir at Reservoir No. 3 on the west side of the river was in all respects similar to that on the east side, it may be assumed that the weir measurements are correct in both cases, taking the heights on the inside of the circular approach.

The steel pipes are composed of 60-in. plates made up in alternate large and small sections, the smaller fitting at each end into the larger. The plates are double riveted on the straight seams, single riveted on the round, and coated with a preparation of asphalt, which rounds off the projecting edges of the joints and tends to lessen the frictional resistance on the pipes. The rivets were not countersunk.

On the 42-in. pipe, the thickness of the plates corresponds to Nos. 6 and 4, B. W. G., except for about $\frac{1}{2}$ mile on which it is $\frac{3}{8}$ in. On the other pipes, 35-in. and 33-in., the thickness is 0.203 in., or No. 6, B. W. G. The diameters are estimated on the inside of the smaller courses, but during the progress of the work it was found that the pressure of the earth filling reduced the vertical and increased the horizontal diameters, the difference being from 1 to 4 ins., according to the depth of the fill and the care exercised in tamping under and around the pipes. To ascertain the effect of this distortion, sections of the pipe were subjected by means of jack screws and loads of earth to external pressures which reduced the vertical diameter within the limits of 1 and 8 ins.; but although without any load there was always a small difference in the transverse diameters, it was found that under any load the mean of the diameters was equal to the diameter of the circular pipe, and that the pipe when relieved from pressure resumed the original form and remained perfectly tight when subjected to a hydraulic pressure of 150 lbs. to the square inch. Assuming the section to be an ellipse the reduction of the area would, under the conditions stated, be inappreciable. Under a heavy water pressure from within, the pipes may have resumed the circular form, but on summits where the water pressure is light, the distortion still remains. The change of section is not apparent to the eye, but it is probable that it exists in all riveted or wrought pipes to an extent depending on the thickness and quality of the plates, the diameters of the pipes, and the depth and character of the filling.

Bends were made by means of joints not more than 6 ins. in width at the widest part, and riveted together in the same manner as the round seams of the pipes, each joint adding a round seam over and above the number required for a straight pipe.

Between the extremities A and D (Fig. 1) of the steel pipe there are two summits, B and C, which break the grade and necessitate pipes of different diameters: 42-in. on A B, 35-in. on B C, and 33-in. on C D.

The section $A B$ extends from the head works A down Bull Run and across the Sandy River to the summit of the divide between that river and Kelly Creek. As the sides of the Bull Run Canyon are high and in some cases nearly vertical, the pipe line is necessarily thrown on high ground with many summits approaching nearly to the hydraulic grade line. From Sandy River to the summit B of the divide between that river and Kelly Creek, the rise is 400 ft. in 4 miles, with grades approaching in places to 45°, as shown on the profile. To avoid slides and vertical cliffs three bridges are necessary, two across Bull Run of 100-ft. and 200-ft. span, and a third of 300-ft. span across Sandy River. The ground is broken and exceptionally rough, requiring many bends, vertical and horizontal. The diameter of this pipe is 42 ins.

The next section extends from B along the north slope of the waters of Kelly Creek to the summit C of Grant's Butte, over broken and rough ground, requiring many bridges and trestles. The diameter of the pipe is 35 ins.

The next section, $C D$, extends from the top of Grant's Butte to the gate house of a reservoir known as No. 1, with no steep grades except the descent from Grant's Butte and the ascent to the reservoir.

From D to a reservoir, G, on the west side of the river, there is a 32-in. cast-iron pipe, and a section, $E F$, of 28-in. pipe passing under the river. The ground is comparatively level, but a considerable curvature is necessary in order to keep the pipe line within the limits of roads and streets.

The bends in the several pipes are as follows:

	Diameters of Pipes. Inches.				
	28	32	33	35	42
Total number of bends	2	17	85	141	225
Total degrees of curvature	21°	800°	404°	782°	1 913°
Average per mile	6°	14°	62°	101°	191°
Extra joints per mile for bends	....	....	11	29	42
Maximum radius	11′	11′	38′	38′	38′
Minimum radius	11′	11′	14′	38′	14′

The lengths of the pipes were calculated from the number of joints and checked by actual measurement. The elevations are measured by spirit level several times during the progress of the work and verified by a survey made recently.

For convenience of reference and calculation, the equations deduced

from the hydraulic formula, $v = c\sqrt{r\,s}$, will be placed under the following forms:

v = velocity in feet per second.

d = diameter of the pipe in inches.

q = discharge in 1 000 000 galls. per day.

n = degree of roughness in the Kutter formula.

c = coefficient of discharge corresponding to n.

h = hydraulic grade, or loss of head per 1 000 ft. of pipe on the hydraulic grade line.

p = piezometer grade or loss of head per 1 000 ft. estimated on the piezometer grade line or lines; p cannot be greater than h, but may have any smaller value according to the discharge.

$$v = \frac{c\sqrt{d\,p}}{219.19} \quad \text{(1)}$$

$$q = \frac{c\sqrt{d^5\,p}}{62\,151} \quad \text{(2)}$$

$$c = q \times \frac{62\,151}{\sqrt{d^5\,p}} \quad \text{(3)}$$

$$p^{\frac{1}{2}} = q \times \frac{62\,151}{c\sqrt{d^5}} \quad \text{(4)}$$

$$o = l \times p \quad \text{(5)}$$

Equation (5) gives the loss of head in a length, l, of pipe.

To determine the discharge, q, through a series of compound pipes.

$$q = \sqrt{\frac{H}{o}} \quad \text{(6)}$$

In this equation H is the vertical distance or available head from the upper to the lower end of the compound pipe, and o is the sum of the losses of head on the several pipes calculated by equation (5) for a discharge of 1 000 000 galls. a day, or for $q = 1$.

TABLE No. 1.—DIAMETERS, HEIGHTS, AND HYDRAULIC GRADES FOR THE STEEL PIPES, $A\,B$, $B\,C$, $C\,D$, AND THE CAST-IRON PIPE, $D\,E$, $E\,F$, $F\,G$.

Pipes.				Elevations above City Base.					
Material.	d.	Section.	l.	Point.	Height.	Point.	Height.	H.	h.
Steel.......	42"	$A\,B$	52 195	A	710.4	B	646.2	64.2	1.213
"	35"	$B\,C$	41 034	B	646.2	C	533.2	113.0	2.754
"	33"	$C\,D$	34 345	C	533.2	D	405.0	128.2	3.733
Cast iron..	32"	$D\,E$	21 460	D	401.8	E	—4.2	406.0	18.890
"	28"	$E\,F$	2 006	E	335.3	F	5.1	9.3	4.650
"	32"	$F\,G$	9 613	F	5.1	G	292.8	287.7	29.928

The city base is 6.18 ft. above low tide at the low-water stage of the Willamette River. The elevations at the upper ends, A and D, of the steel and cast-iron pipes are corrected by deducting the head lost in generating the velocity. The elevation of D, 405, at the end of the steel pipe is the height of the water above the weir, but for the upper end of the cast-iron pipe it is the surface of the water below the weir. At the ends of the pipes the elevations are estimated to the tops of the pipes or to the surface of the water.

On February 27th, 1896, with the elevations of the water surfaces at A, D and G, as given in Table No. 1, the discharge was 23 500 000 galls. through the riveted pipes, and 20 750 000 galls. through the cast-iron pipe.

The 42-in. pipe did not run full beyond a point A' at an elevation of 648.5 ft., and 1 950 ft. east of the junction B of the 42-in. and 35-in. pipes.

The 35-in. pipe was partially full at the upper end, and at a point B', 1 205 ft. west of B, the elevation of the hydraulic grade was 633.1 ft., by piezometer measurement. The elevation of the water surface was 532.5 at the junction of the 35-in. and 33-in. pipes, beyond which the 33-in. pipe was only partially full. At a point C' on the 33-in. pipe, 163 ft. west of C, the elevation of the hydraulic grade was 527.1 ft. by piezometer measurement.

On the compound cast-iron pipe, the elevations in Table No. 2 are those of the piezometer grades, calculated by equation (6). For the steel pipes the coefficients are calculated from the hydraulic grades.

TABLE No. 2.—DIAMETERS, GRADES AND COEFFICIENTS OF THE STEEL PIPES, $A\ A'$, $B'\ C$, $C'\ D$, AND OF THE COMPOUND CAST-IRON PIPE, $D\ E$, $E\ F$, $F\ G$.

PIPES.				ELEVATIONS ABOVE CITY BASE.							
Material.	d.	LENGTH, l. Section.	LENGTH, l. 1 000 ft.	Point.	Height.	Point.	Height.	H.	h.	q.	c.
Steel....	42"	$A\ A'$	50.965	A	710.4	A'	648.5	61.9	1.215	23.5	115.9
"	42"	$A'\ B$	1.950	......	......	......	......	......	......	......	......
"	35"	$B\ B'$	1.205	......	......	......	......	......	......	......	......
"	35"	$B'\ C$	39.829	B'	633.1	C	532.5	100.6	2.526	23.5	126.8
"	33"	$C\ C'$	.169	......	......	......	......	......	......	......	......
"	33"	$C'\ D$	34.176	C'	527.1	D	405.0	122.1	3.572	23.5	123.2
Cast iron.	32"	$D\ E$	21.460	D	401.8	E	335.3	66.5	3.100	20.75	126.2
"	28"	$E\ F$	2.006	E	335.3	F	322.6	12.7	6.340	20.75	123.4
"	32"	$F\ G$	9.613	F	322.6	G	292.8	29.8	3.100	20.75	126.2

Assuming p equal to h, and the lengths and grades to be as given in the preceding tables, the values of C and q for clean straight pipes, according to Hamilton Smith, M. Am. Soc. C. E., and J. T. Fanning, M. Am. Soc. C. E., and for $n = 0.0115$ in the Kutter formula, would be as follows:

TABLE No. 3.

$d.$	$h.$	SMITH.		FANNING.		KUTTER.			TABLE No. 2.
		$c.$	$q.$	$c.$	$q.$	$n.$	$c.$	$q.$	$c.$
42"	1.213	137.0	27.75	129	26.73	.0115	130	26.38	116
35"	2.754	136.5	26.41	125	24.19	.0115	124	24.00	127
33"	3.733	136.0	26.45	124	24.11	.0115	124	24.11	123
32"	3.100	135.0	22.15	123.5	20.26	.0115	123	20.19	126
28"	6.240	134.0	22.52	121	20.33	.0115	121	20.33	123

With the coefficients corresponding to $n = 0.0115$, the values of p, and the discharge of the compound 42-in., 35-in. and 33-in. pipes, calculated by equation (6), would be as follows:

TABLE No. 4.

$d.$	$c.$	LENGTH.			Head lost. $o = l \times p.$	ELEVATIONS OF GRADE.				$q.$
		Section.	1 000 ft.	$p.$		Point.	Height.	Point.	Height.	
42"	130	*A B*	52.915	1.048	55.2	*A*	710.4	*B*	655.2	24.5
35"	124	*B C*	41.034	2.871	117.9	*B*	655.2	*C*	537.4	24.5
35"	124	*C D*	34.345	3.852	132.3	*C*	537.4	*D*	405.0	24.5
		Total head lost............			305.4	=	710.4 — 405.0			

The actual discharge, 23 500 000 galls., is 1 000 000 galls. more than was ordered, and 1 000 000 galls. less than would have been attained if the capacity of the 42-in. pipes had been proportional to that of the 35-in. or 33-in. pipes.

Of the three steel pipes the 33-in. was the straightest, and the coefficient should not have been 3% below that of the 35-in. pipe. The 42-in. pipe was over very rough ground, with many bends and summits, some of which rise very nearly to the line of the hydraulic grade, but the minimum radius of curvature was four times the diameter of the pipe, and there is no apparent reason for the reduc-

tion of the coefficient and discharge to 10% less than it would have been on the supposition that the conditions were the same as those of the other riveted pipes.

When the water was first turned on, in December, 1894, the height of the water surface at the head works was about 710.4 ft., and the discharge by the floating gauge at the end of the 33-in. pipe was 24 900 000 galls., but as it has since remained steadily at 23 500 000 galls. under like conditions, either the gauge must have been out of adjustment or air must have accumulated at some of the numerous summits.

The air valves which have been placed on all summits have been examined; men have been sent through the whole length of the pipe to see that there were no obstructions, and that the 42-in. gate below the trumpet-shaped mouth-piece at the head was fully open; and the screens have been raised to see that they did not diminish the flow, but, although some of the flatter summits may have escaped observation, nothing has as yet been discovered which accounts for the deficiency in the capacity of the pipe.

It will be seen by reference to Table No. 3 that, except for the 42-in. pipe, the coefficients are about the same for the cast-iron and steel pipes, and agree nearly with the coefficients of Mr. Fanning for clean pipes and those of the Kutter formula, for $n = 0.0115$.

A. L. Adams, M. Am. Soc. C. E., engineer of the water-works recently constructed in Astoria, Ore., informs the author that the supply main there is compounded of a 16-in. steel riveted pipe and an 18-in. wood-stave pipe; that the coefficient for the former corresponds almost exactly with the value given by Mr. Fanning for clean, straight cast-iron pipes, and to the value $n = 0.0113$ in the Kutter formula, and is only 83% of the coefficient for the 18-in. stave pipe.*

The riveted pipes on which the experiments of Mr. Smith were made were put together stove-pipe fashion, and the high coefficients deduced may be due in part to the lesser frictional resistance resulting from this method of construction, but the projecting edges of the laps on the inside of a pipe are smoothed and rounded by the asphalt coating, and the increase of friction resulting from constructing the pipes in rings with large and small sections does not appear to be important, when the thickness does not exceed ¼ in.

* See *Proceedings*, April, 1896.

The assumption on which the preceding calculations are based, that the piezometer grade p, which would be the grade of a line along the water surfaces in a series of open-topped tubes extending upward from the pipe, coincides with the hydraulic grade h of a straight line from the upper to the lower end of a pipe is true only when the inner surface opposes a frictional resistance which is uniform throughout the whole length of the pipe. In such cases the coincidence of the grade lines depends solely on the uniformity and not on the amount of the frictional resistance. The discharge depends on the amount of the friction, and is proportioned to coefficients of discharge determined experimentally and corresponding to the roughness n in the Kutter formula.

According to the principles of the Kutter formula the coefficient c is independent of the slope in the equation $v = c\sqrt{r\,h}$, when r is greater than 0.1 ft. and h is greater than 1 ft. in 1 000 ft.

According to experiments on the flow of water through pipes the variation of the coefficient is greater, but the difference may be due, in part at least, to the use of the term in a sense not warranted by the conditions of flow in open channels.

In the case of an open channel with a constant discharge and with irregular cross-sections or a variable roughness of the sides and bottom, the velocity and volume of the water vary in accordance with the slopes and the resistances to the flow in different sections of the channel, and an obstruction placed in one section does not diminish the discharge or appreciably affect the velocity or volume of the flow in other sections, except for a short distance above or below the obstruction. In the case of a full pipe there can be no difference in the velocity or sectional area of the water, and an obstruction to the flow at any one point is followed by a change in the pressure against the inner surface at all points, which would affect the piezometer grades along the whole length of the pipe, and has the same effect on the discharge as a change in the hydraulic grade.

To calculate the flow of water in open channels by hydraulic formulas the hydraulic grade h must be used, and for pipes the piezometer grade p, which may be less, but cannot be greater than h.

A pipe laid on the hydraulic grade line $A\ B$ would run full with a discharge q, given by equation (2), and a grade h, and only partially full with a less discharge q'. Should the pipe be laid under the hy-

draulic grade line, it would run full with the discharge q', but the grade would be reduced to p', calculated for the lesser discharge by equation (4).

Suppose two pipes with the same diameter and hydraulic grade, with discharges q and q' (the first calculated from the hydraulic grade), the reduction of the discharge from q to q' could be attributed to a greater roughness corresponding to a coefficient c', or to a change from the hydraulic grade h to the piezometer grade p', given by equation (4), and the values of c' and p' would be determined by the following equations, assuming the grades and coefficients to be independent quantities.

$$c' = c\,x\,\frac{q'}{q} \text{ when } p' = h \ldots\ldots (a)$$

$$p' = h\,x\,\left(\frac{q'}{q}\right)^2 \text{ when } c' = c \ldots\ldots (b)$$

The discharge would be the same in either case, but the pipe, if laid in the hydraulic grade, would run full with a roughness corre-

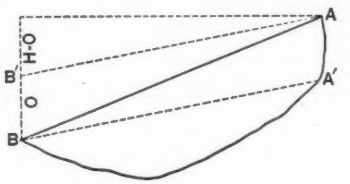

FIG. 2.

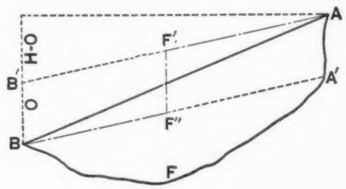

FIG. 3.

sponding to c' in equation (a), and partially full with the grade p' in equation (b), and a roughness corresponding to the coefficient c.

Should the discharge be decreased from q to q' through an open-topped pipe with a hydraulic grade line $A\,B$ (Fig. 2), the water would fall to a hydraulic grade line $A'\,B$, and the grade would be given by equation (4).

Suppose H to be the vertical fall from A to B, O the vertical fall from A to A', and l and k to be the lengths of the pipes $A\,B$ and $A\,A'$, the grade $h' = p'$ would be given by either one of the following equations or by equation (4):

$$p' = \frac{H - O}{l - k} = h\,x\,\left(\frac{q'}{q}\right)^2 \ldots\ldots (c)$$

Suppose k to be small in comparison with l, the equation would be:

$$p' = \frac{H - O}{l} = h - o = h\,x\,\left(\frac{q'}{q}\right)^2 \ldots\ldots (d)$$

Should the supply be taken from a reservoir with a surface level fixed at A (Fig. 3), the hydraulic grade could not change, but the piezometer grade would be reduced from h to $h\, x \left(\frac{q'}{q}\right)^2$.

Should the loss of head O be due to the partial closing of a stop valve F, causing a vertical fall in the piezometer line below F, the grades would be on the parallel lines $A' B$ or $A B'$, should the valve be placed at A or B, and on the lines $A F'$, $F'' B$, should it be placed between A and B. In the latter case the grade lines would be on different sides of $A B$, but in each case O would be the vertical distance between the parallel grade lines; the grade p would be given by equation (d), and the pipe, if laid on the grade h, would be only partially full below the obstruction.

In these examples the whole loss of head has been supposed to take effect at one point, F, but should there be obstructions at several points, O would still represent the sum of the losses. The piezometer grades would descend in parallel lines between the obstructions like the steps of a stairway, and although there might be a considerable difference in the grades, the lines might continue close together, and would tend to coincide should the losses of head be equal and at uniform distances apart.

To the assumption that the piezometer grade is on the straight line between the heights of two points in the piezometer grade lines may be ascribed the variation in the coefficients deduced from piezometer measurements, so called.

For a series of compound pipes the loss of head for each one is determined by equation (5), and the discharge must be such that the sum of the losses in the several pipes must be equal to the total loss of head or vertical fall H from the upper to the lower end of the compound pipe, subject to the condition that the pipe must not rise at any point above the piezometer grade line. Examples are shown in Table No. 4 in the case of the 42-in., 35-in. and 33-in. pipes, and in Table No. 2 in the case of the compound 32-in. and 28-in. cast-iron pipe.

In a compound pipe the resistance to the flow of water in the several parts varies with the diameters, the degrees of roughness, and the local obstructions, and the piezometer grades fall in parallel lines on sections of uniform resistance, and vertically in the cases of local obstruc-

tions, like the surface of the water of an open channel, but with the important distinction that while in one case the grades depend on the actual slopes in the different sections, in the other they are due to variations in the pressure from obstructions on the inner surface, the effect of each one of which is felt throughout the whole length of the pipe.

It follows that when the two end sections of a pipe present equal and uniform resistances to the flow, the piezometer grade lines must lie on different sides of the hydraulic grade line, *A B* (Fig. 4), and must cross it at one or more points, and that the coefficients calculated on the assumption of a straight grade line do not indicate the roughness of the inner surface.

The hydraulic grade line *A A′ B* (Fig. 5), for instance, of the 42-in. riveted pipe falls at the rate of 1.213 ft. per 1 000 ft. to a summit *A′* west of the Sandy River, and the pipe is extended thence, along the hydraulic grade line, 2 000 ft. to a point *B*, at the end of the pipe.

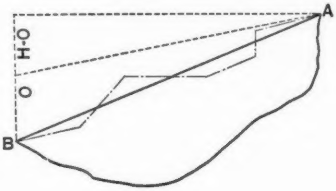

FIG. 4.

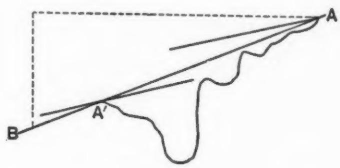

FIG. 5.

With a coefficient $c = 130$ (see Table No. 3), corresponding to the roughness of the 35-in. and 33-in. pipes, and to $n = 0.0115$, the discharge would have been 26 380 000 galls. in 24 hours, but it was only 23 500 000 galls. If the deficiency is due to the uniform roughness of the inner surface, the pipe would run full on the hydraulic grade line $A' B$, and the coefficient $c' = 130 \times \frac{23.50}{26.38} = 116$ would indicate a roughness equal to 0.0125. But the fact that the pipe does not run full from A' to B shows that the roughness is less than 0.0125 and that the grade is less than the hydraulic grade, and the reduction of the discharge may be ascribed to a reduction of the grade from $h = 1.213$ to $p' = h\, x \left(\frac{23.50}{26.38}\right)^2 = 0.963$, on account of bends, accumulations of air at summits, or causes not connected with the degree of roughness or the coefficient of discharge.

A difference of 3 ins. in 1 000 ft. could not be detected readily, but measurements by pressure gauges show conclusively that the piezometer is above the hydraulic grade line at A and below it at A', and that the two lines cross at one or more intermediate points.

The difference of the grades multiplied into the length of the pipe, $o = (1.213 - 0.963) \times 52.9 = 17.6$, is the vertical distance between the parallel grade lines through A and A' and represents the total loss of head from irregular obstructions; but the difference in the elevations of the two grade lines, as measured by pressure gauges, does not at any point exceed 3 ft. Assuming, then, that there must always be a diminution of the grade from irregular obstructions, it will follow that the coefficients calculated by using the hydraulic grade in equation (3) are always too small, especially when o is small in comparison with h, and this may perhaps account for the great variation where the grades are light.

In Table No. 5 coefficients calculated from hydraulic grades are given from Mr. Fanning's tables and from the measurements of the 48-in. cast-iron pipes of the Boston Water-Works*; also the value of o in the equation, $p = h - o$, which would give a uniform value to the coefficients. The grades are in feet per thousand.

TABLE No. 5.

Authority.	Diameter, inches.	Grade. h.	c.	Grade. $p = h - o$.	c.	Pipes.
Fanning........	6	1.409	98.3	$h - .020$	105	Clean straight.
"	6	2.976	101.7	$h - .032$	105	"
"	6	3.827	102.7	$h - .047$	105	"
FitzGerald......	48	0.0115	116.5	$h - .003$	144	Clean.
"	48	0.0689	134.1	$h - .009$	144	"
"	48	0.3251	137.5	$h - .030$	144	"
"	48	0.7182	138.9	$h - .050$	144	"
"	48	1.2414	141.1	$h - .050$	144	"
"	48	1.8283	143.6	$h - .057$	144	"
"	48	0.0159	101.3	$h - .002$	110	Tuberculated.
"	48	0.0202	88.1	$h - .007$	110	"
"	48	0.5158	108.7	$h - .002$	110	"
"	48	1.1308	109.4	$h - .012$	110	"
"	48	2.6368	108.9	$h - .054$	110	"
Smith..........	42	1.213	116.0	$h - .250$	130	Steel riveted.

The coefficient 144 in the table is the same as that determined by Mr. FitzGerald for the 48-in. pipes with tubercles removed and a velocity of 6.195 ft. per second, but for the tuberculated pipes no definite conclusion can be drawn where the grades are very small, the

* See *Proceedings*, January, 1896.

coefficients being 114.8 in one case, for a slope of 0.0287 per 1 000, and 88 in another instance for a slope of 0.0211. This difference may be ascribed to the liability to error in measuring very small slopes, but for greater grades there does not seem to be so great a variation in the coefficients as with the clean pipes, which tends to support the principle of the Kutter formula that, except for very small slopes, the coefficients are constant for the same diameter of pipe, which would be more apparent should the slopes and coefficients be used as co-ordinates in diagrams, and the velocities be left out of consideration, or treated as functions of the grades. The effect of a small difference in the grades on the discharge will show the necessity of accurate measurements where the grades are light and the pipes not more than 1 000 or 2 000 ft. in length. For the 42-in. pipe, for instance, a difference of 3 ins. in 1 000 ft. makes a difference of nearly 3 000 000 galls. in 24 hours.

In regard to the effect of long use on the tuberculation of the inner surfaces of pipes, the following information is presented from experience with the pipe system of the city of Portland. The supply was first taken from small creeks, to which was added 28 years ago a plant for pumping from the Willamette River, which carries a large amount of mud and sand during floods. The use of this plant was afterward discontinued and a new pumping station erected 12 years ago, with a 4-mile force main of 30-in. riveted pipes of No. 6 wrought iron. The pump main laid 28 years ago was 18 ins. in diameter and of No. 6 wrought iron. It was laid on trestles across ground overflowed at high water, and was not protected from the weather. The coating was displaced on some portions of the pipe, but otherwise it appears perfectly clean and sound, and portions are now being used in the distribution system of the city under a pressure of 90 lbs. to the square inch. A portion of the 30-in. riveted pump main was taken up, and the coating was found to be intact and the pipe perfectly clean and sound. The cast-iron pipes from 6 to 24 ins. in diameter are free from tuberculation, so far as can be ascertained. The only exception is a 4-in. pipe which has been in use for 15 years and is rusted and rough on the inside, but it does not appear that this pipe was coated.

The Bull Run water is probably of the same nature as that of the Willamette River, except that it is always clear, and it is not probable that it will have a different effect on the pipes.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

PAPERS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

A WATER POWER AND COMPRESSED AIR TRANSMISSION PLANT FOR THE NORTH STAR MINING COMPANY, GRASS VALLEY, CAL.

By Arthur De Wint Foote, M. Am. Soc. C. E.

To be Presented at the Annual Convention, 1896.

Upon the prohibition of placer mining by the State of California, the immense canal systems extending over the western slopes of the Sierra Nevadas were left without a purpose, and their future existence depended upon a new use for water. Out of this necessity has grown a business of selling water for power and irrigation, retaining the original methods of delivery at the bank of the canal and miner's inch measurement. The price of water is approximately 1 cent per 1 000 galls. delivered at the canal; its cost for power depends upon the pressure that can be obtained from it. In the case of the North Star plant, it could have been conveyed directly to the mines and have done its work there on different wheels more or less adapted to the varying conditions; but there is a certain inconvenience and danger in using water in this manner under a high pressure, and, moreover, the mines are on a

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

hill. So it therefore seemed advisable to convey the water directly to the lowest convenient point, obtain the power there, and transmit this power to the places where it was needed.

This brought forward the subject of transmission of power, and electricity was naturally suggested first. Visits to mines in operation and careful study and investigation of electrical appliances for underground work, especially pumping, finally decided the author in favor of compressed air. The latter method, under the conditions, was believed to be most economical of power, least liable to accident, and cheapest in first cost. Moreover, almost absolute security against stoppage could be obtained by having a set of boilers on hand ready for firing up in case the water power or air plant gave out, for, by the use of these boilers and opening and shutting a few valves, all the air motors become equally good steam motors; whereas, with electrical transmission an entire set of steam motors would have to be provided to give equal security; or, as the air and steam motors are the same, the electrical motors would require just so much extra expense in cost of plant of equal security against stoppage.

To give as briefly as possible a distinct idea of this work, a concise description of the whole plant is first submitted, followed by the detailed presentation of its several parts, and, finally, the results obtained after careful tests during three months of actual working.

The water supply is obtained from the South Yuba Water Company, at a point on their canal about 4 miles from Grass Valley, Nevada County, Cal. Thence it is conveyed about 2½ miles to the Empire Mining Company's works in a 22-in. riveted iron pipe, built more than ten years ago. The new conduit is a riveted steel pipe, 20 ins. diameter, joined to the lower end of this old one under a head of 420 ft., and continues 7 070 ft. to the power house, situated at the lowest convenient point on Wolf Creek, just below the town of Grass Valley, where a head of 775 ft., or a static pressure of 335 lbs. per square inch, is obtained. The capacity of this pipe is sufficient to develop 800 to 1 000 H. P.

At the power house there is a Pelton water wheel 18 ft. 6 ins. diameter, running on a 10-in. shaft, to which a duplex compound air compressor is connected directly. The initial cylinders are 18 ins., and the second cylinders are 10 ins. in diameter, with a 24-in. stroke. They were designed to run at 110 revolutions per minute, and require 283 H. P. from the water wheel.

A 6-in. lap-welded pipe conveys the air at 90 lbs. pressure from the power house to the company's Stockbridge shaft on Massachusetts Hill, 800 ft. distant and 125 ft. higher. Here it is now being used in a 100-H. P. cross-compound Corliss pneumatic hoisting engine, and a 75-H. P. compound pump, beside other pumps, blacksmith forge, drills, etc,

The Pipe Line.—The line of the pipe is quite crooked, both horizontally and vertically, partly because it was necessary in locating it to follow a county road. The trench was dug with plows and scrapers, except where too stony, and the joint holes were dug by hand. The joint holes cost fully as much as the trench, for the reason that many of them reached down to the harder and rockier stratum below the soft surface material. The trench was about 10 ft. wide on top, 4 to 5 ft. on the bottom, and 4 ft. deep. The joint holes were 4 to 5 ft. long and 3 ft. deeper than the trench. The total cost of all the work of burying the pipe, including covering a large portion of it with stone from the mine dumps, and cement masonry wells for the valves and for sustaining the pipes around bends, amounted to approximately $6 756.27. This was done on company account, after refusing bids, the lowest of which would have amounted to about $8 500.

An aqueduct of cement masonry across Wolf Creek at the power house is not included in this estimate, but was built on company account. As shown in Plate IX, Figs. 1 and 2, it was first built up to grade; the pipe was then laid upon it and afterward covered, so that the pipe is now in the center at the tops of the arches, where the masonry section is 4 ft. square. The piers of this aqueduct are carried down to the bed-rock of the creek some 8 or 10 ft. below its water level. The lower portion of the center piers was built up of cement concrete, but the remainder of the bridge is built of the rough stone hauled from the mine dumps in the vicinity, and Portland cement and sand mixed one to three. Very little hammering was allowed, mortar being cheaper than masons. The center arches are of 33-ft. span, and the other two of 24 ft. and 28 ft., the length of aqueduct over all being 153 ft. The rock and sand each cost 75 cents per yard delivered; common labor, $2.50 per day; masons and foreman, $4 per day. The entire cost of the bridge was $1 435; as it contains about 180 cu. yds., the cost per yard was about $8. It is thought that this will prove cheaper in a few years than any other mode of carrying the pipe across the creek.

PLATE IX.
PAPERS AM. SOC. C. E.
MAY, 1896.
FOOTE ON COMPRESSED AIR TRANSMISSION PLANT.

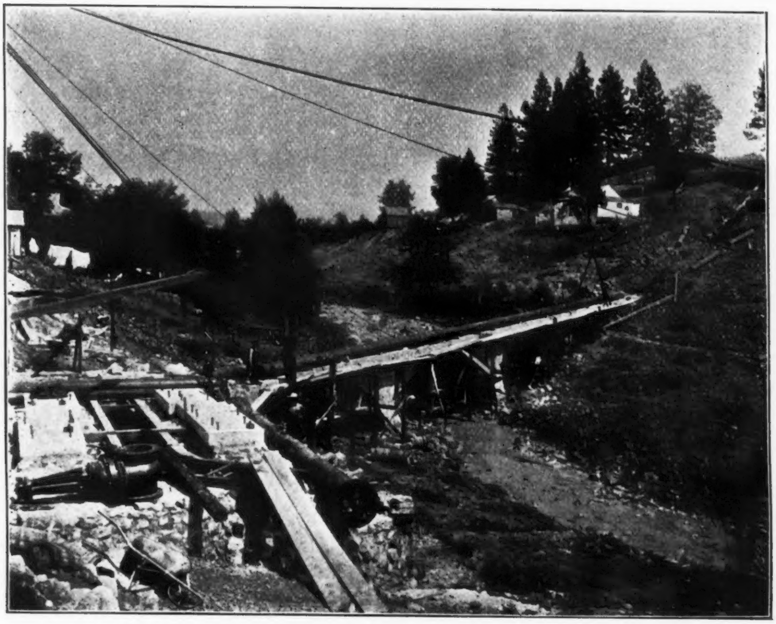

FIG. 1.

FIG. 2.

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Wood or even iron would be subject to more or less change of form, sufficient to cause leakage in the pipe, but it is believed that the pipe buried in the masonry, when once tight, will never have movement enough to cause leakage. In any case, it is probable that a wooden truss bridge with stone piers would have cost nearly as much as the stone. It should be mentioned, however, that the lumber for centers is not included in the cost in this case as it could be used equally well afterward in the mine.

The steel slabs for the pipe were furnished by the Pennsylvania Steel Company. The Central Mills of Harrisburg rolled the plates, and only seven sheets of the entire lot were rejected by the inspector. The Risdon Iron and Locomotive Works of San Francisco manufactured the pipe from the 48 x 66-in. sheets and laid it complete in lengths of about 28 ft. in the trench under the following schedule, the longitudinal seams being double riveted by hydraulic riveters:

Head in Feet.	Length.	No. B. W. G.	Thickness.	Rivets.	Remarks.
420 to 500	2 320 ft.	9	0.148 in.	$\frac{3}{8}$ in.	Cold riveted
500 to 600	2 110 ft. 6 ins.	8	0.165 in.	$\frac{3}{8}$ in.	"
600 to 700	1 158 ft.	7	0.180 in.	$\frac{7}{16}$ in.	"
700 to 750	1 204 ft.	6	0.203 in.	$\frac{1}{2}$ in.	Hot riveted
750 to 775	285 ft.	5	0.220 in.	$\frac{1}{2}$ in.	"
Receiver	40 ft.	....	0.375 in.	$\frac{9}{16}$ in.	"

The specifications required a mild and very tough steel, and the cold flat bending test was insisted upon for all thicknesses. The pipe was dipped after being made into lengths into the usual hot asphaltum mixture, and then shipped by rail to Grass Valley and delivered along the trench in wagons. It was then rolled into the trench, and the lengths riveted together in place. Where there was no change in direction a slip joint was made by raising the outer end of the length with a small hand derrick, slipping the upper side into the completed portion, and catching it there through the rivet holes with bolts. Then by lowering the outer end, the weight forced the length into its place with a little care and guidance by chisels, when it was bolted ready for the riveters. Where there was a change in direction, bands were put on in two halves, lapping, but no bend piece or band was allowed with more than 4 ins. difference in width between the inside and outside. Where hot rivets were used a $\frac{3}{4}$-in. hole was punched in the top of the pipe near the end, through which the hot rivets were

dropped to the holder-on inside. This hole was afterward stopped with a ¾-in. gas-pipe plug. P & B paint was used to cover all points not protected by the original asphaltum mixture, because it was considered preferable to the hot mixture when put on the cold metal.

In filling the pipe with water, it was quite a delicate operation to let on the full pressure at the Empire gate, as it added 180 lbs. pressure per square inch the instant the lower 7 000 ft. became full. It was done several times by keeping open a valve at the lower end of the pipe, while the Empire gate was allowing a little more to pass than the lower valve allowed to run away. In this way the pressure was not raised more than 10 or 15 lbs. above the normal. Numerous very small leaks appeared in the pipe under pressure, but neither then nor since has there been a defective rivet or plate. Fine dust from the wagon road was put into the pipe in considerable quantities, which stopped most of the smaller leaks or sweating. The attempt was made at first to mark the larger leaks, and then take off the pressure and calk them, as in the case of a steam boiler. It was soon found, however, that they would appear again as soon as the pressure was returned. Since the leaks have been calked under pressure, using proper care not to strike heavy blows, all trouble has ceased. For a time, owing to an imperfect gate at the Empire, the pressure was raised 60 to 90 lbs. almost instantly many times a day, and in consequence small leaks developed, though they were easily calked.

Close watching was necessary, however, as a stream no larger than a hair, if it happened to be turned along or against the pipe, would, with the aid of the sand it washed in, cut the pipe badly in a few hours. In one instance two threads of water, so small that they failed to wet the earth upward to the surface, shot out at right angles to each other, one from the longitudinal seam, and one from the circular seam near their intersection. These streams, striking each other, formed a miniature whirlpool, which bored a hole through the pipe about the size and shape of the point of a lead pencil, letting out a larger stream which soon led to its discovery. Where sharp bends were necessary, the pipe, as laid in the trench, was packed on the outer side of the bend by grouting and cement masonry between the pipe and the side of the trench for the full thickness of the pipe.

About 1 000 ft. from the lower end a 12-in. branch with a gate is put in for possible future use, and adjoining it on the lower side a

20-in. gate. These are buried in cement masonry, to prevent any movement from thrust when the latter gate is closed, and over all is built a cement masonry gate house 12 ft. square, which answers also for a tool house. At the lower end of the pipe in the power house there is another 20-in. gate, below which is a 12-in. branch leading to the Pelton wheel, and adjoining this is the receiver, 2 ft. in diameter, on which are the air chambers, charging tube and relief valve. The lower end is stopped with a flanged end, bolted on, which can easily be removed for extending the receiver for additional power.

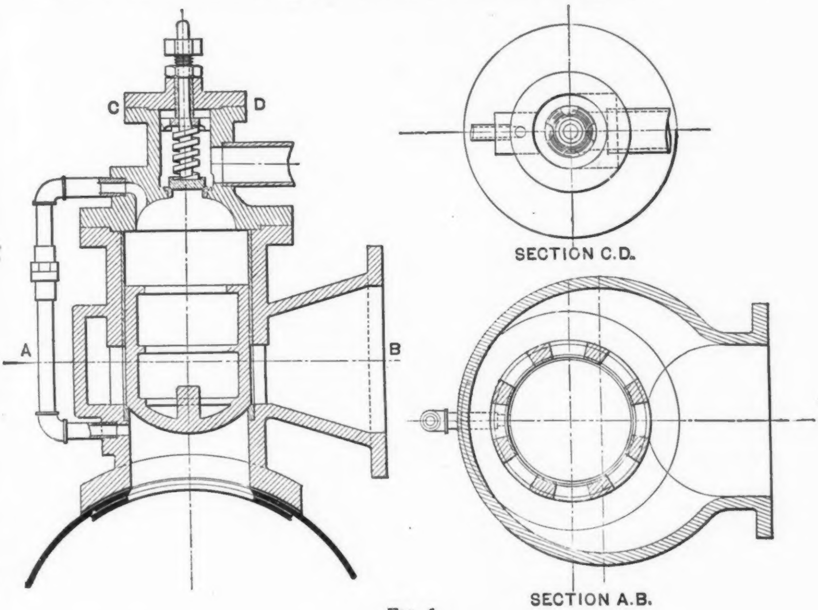


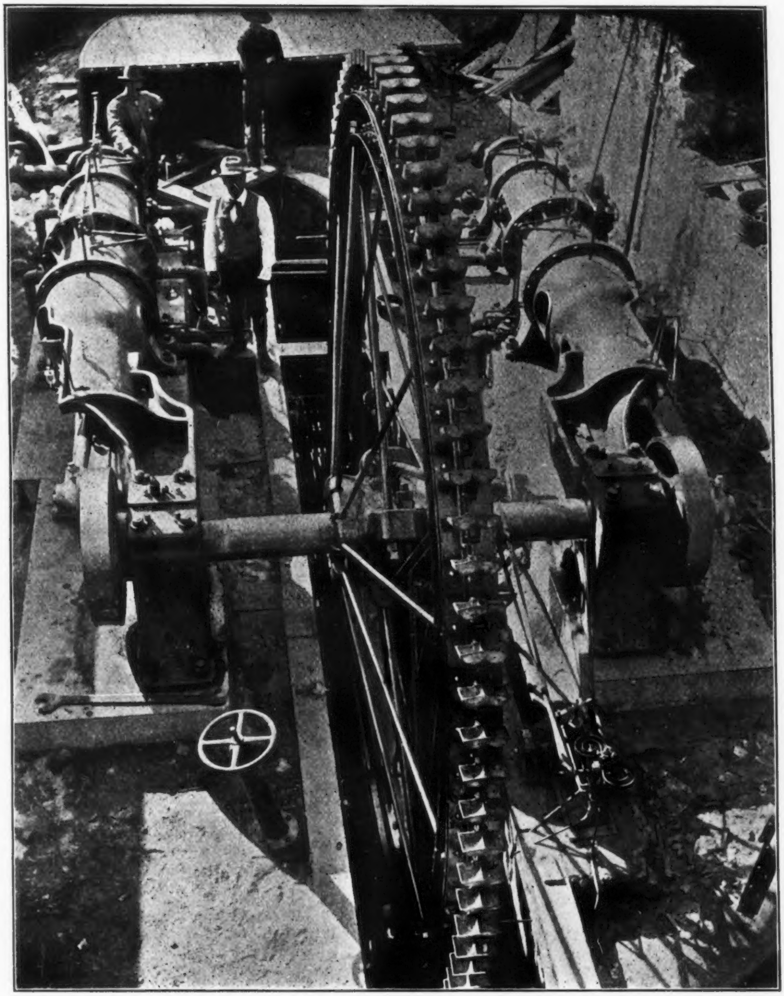
FIG. 1.

The air chamber is a 10-in. lap-welded tube 18 ft. long standing on the receiver, with an 8-in. gate between. The charging tube is similar, but 8 ins. in diameter. Both have 2-in. water discharge pipes and gates, and by proper manipulation of the gates and the operation of inlet check valves on top of the tubes, the air chamber may be filled. Ordinarily the charging-tube is filled up to 90 lbs. pressure from the air compressor delivery pipe, and then raised by the water pressure. It is found necessary to put in about one-tenth of the volume of the air-chamber every day. Where the air goes is, thus far, a mystery, as no leak has been discovered.

The relief valve was designed by Mr. H. Schussler, Chief Engineer of the Spring Valley Water-Works of San Francisco, and is the first of its kind ever made. It is shown in Fig. 1. It seems perfect for the purpose, except that the small pop-valve leaks continually. It is hoped that this fault may be remedied by using a different form of valve. It can be set to open at about 35 lbs. above normal, and will close without jar or hammer. In action, the pressure rises until it lifts a pop-valve in the ordinary way; when this is raised the pressure is relieved on top of an 8-in. piston, slightly larger at the top end, which rises and opens the ports of an 8-in. outlet. The pressure going down, the pop-valve closes and equalizes the pressure on both ends of the piston, gradually closing it. If the proper pop-valve can be procured, this relief valve will prove a sure safeguard for the pipe. On one occasion already, when from some unknown source a piece of drift wood entered the nozzle and stopped the flow of water instantly, this relief valve saved the pipe from serious shock, if not actual bursting.

Water Wheel.—The demand for direct action under a head of 775 ft. made a large wheel necessary in order to obtain the proper peripheral speed of half the spouting velocity. The manufacturers objected seriously to undertaking anything over 15 ft. in diameter; whereas the proper speed of 60 to 70 revolutions for the compressors required a wheel of nearly 30 ft. diameter. A compromise was finally made with a wheel of 18 ft. 6 ins. diameter, and a compressor revolution of 110 per minute, and the Pelton Water-Wheel Company, of San Francisco, built the wheel from a design by Mr. E. S. Cobb. Had the design been prepared sooner, the wheel could have been made 30 ft. in diameter equally well. The Pelton Company guaranteed an efficiency of 85% at full load, and an average of 75% from half to full load of the theoretical power of the water, and, at the same time, to so govern the wheel that it should not exceed 120 revolutions nor raise the air pressure above 105 lbs. per square inch in case of accident to machinery or sudden shutting off of air. As shown in Plate X, the rim is built up of angles and plates riveted together to break joints. It weighs about 6 800 lbs., and is held concentric with the shaft by 12 pairs of radial spokes of 1¼-in. rod iron held by nuts to the cast-iron hub. The driving force, being applied to the rim, is transferred to the hub by four pairs of 2-in. iron rods, so arranged as to form a truss, shown

PLATE X.
PAPERS AM. SOC. C. E.
MAY, 1896.
FOOTE ON COMPRESSED AIR TRANSMISSION PLANT.



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also in Plate X. Without going into the calculations for strains, which are given as furnished by Mr. Cobb in Appendix No. 1, it may be stated that the factor of safety is very large for all the strains likely to come on the wheel.

The wheel is set on a 10-in. shaft, having a disk crank on either end connected directly to the compressors. The wheel was easily lined up by the nuts on each end of the radial spokes to run almost perfectly true. After a few weeks' use it was found to have worked slightly and was straightened again. It balanced so well that upon shutting off the water it was 14½ minutes coming to rest from 110 revolutions per minute, when disconnected from the compressors. The regulator is a floating valve actuated against excessive velocity by the ordinary ball governor and against excessive air pressure by a spring set to move when the air pressure in the delivery pipe exceeds 90 lbs. This floating valve admits water on either end of a hydraulic piston which operates a lever moving a hood up and down over the head of the nozzle, thus shutting off or letting the water on to the wheel as the air pressure becomes too great or as the speed gets above or below 110 revolutions. This regulator has now operated the wheel for several weeks and seems almost human in handling its speed. The load can be thrown off entirely and the governor will hold the wheel to 120 revolutions or less, and if all the air motors happen to be shut down the air pressure will increase rapidly and the wheel slow down, until at 100 lbs. it will stop.

The compressors are so arranged, as will be shown further on, as to admit of being run at one-quarter, a half, three-quarters or full power. It was quite an object, therefore, to have a water wheel which would give as nearly as possible the full efficiency under these different heads. For this purpose there are four nozzles, one for each of the heads required, and, as the machine must be stopped to change its capacity from one load to another, it is no great inconvenience to change nozzles at the same time, requiring perhaps three minutes. It was of considerable interest to know just what the efficiency of so large a wheel might be, and it was also necessary to measure the water quite accurately for business purposes; therefore a measuring flume 18 ft. long and 6 ft. 9 ins. wide was constructed to take the tail water on leaving the building. The overflow is a sharp-edged iron about 3 ins. high and 15 ins. above the bottom of the flume. No contractions are made.

An 8-in. pipe about 6 ft. above the overflow connects with the gauge box, within which is the measuring scale for the hooked gauge. Great care was used in making the whole apparatus as perfect as possible, and it is believed that the average result of many measurements is within 1% of being correct. The power developed by the wheel was found by taking a large number of indicator cards from the compressors. These were averaged and the friction added, which was found by first running one compressor and afterward running it with the other compressor with the valves out; the difference in the quantity of water used was measured and the horse-power of this water was called two-thirds of the friction of the machine when loaded, which was equivalent to allowing 50% for load. The friction of the water wheel and its bearings is included in its efficiency. Repeated tests which checked very closely give the wheel an efficiency of a trifle over 90% for one-quarter, one-half, three-quarters and full loads. Between these points it is somewhat less, as the hood coming down over the nozzle tends to deflect the water as well as hold it back, and decreases the efficiency. It seems probable that the long radius of the wheel accounts for the high efficiency.

The illustration of the wheel shown in Plate X was taken before the wheel was tried. The buckets were soon found to be too near together, and one-half of them were taken off. Actual working has shown that this wheel has great efficiency at low speed. It began working under half load, using the half-load nozzle. Gradually in pumping out the mine, as the pumps were lowered and more power was needed, the limit of the machine while running one compressor at 110 to 115 revolutions was reached, and the opposite compressor was connected on, the intention being to run three-quarters load with the three-quarter nozzle. As an experiment, both compressors were connected as if for full load, and the half-load nozzle was retained. The result showed considerable more power delivered with both compressors running at 54 to 65 revolutions than was obtained before with one compressor at 115 to 120, so much, indeed, that the works were kept running over two weeks longer with the half-load nozzle, though the pumps were lowered on an average of 18 ins. per day. Of course a large portion of the gain in power can be attributed to the saving in friction and improved working of the compressors under the slow motion, but yet it must be true that the wheel loses very little in its effici-

ency, compared with the accepted ideas of loss in wheel efficiency, working under a peripheral speed of one-quarter of the spouting velocity.

Compressors.—Mr. E. A. Rix, of San Francisco, who has made a careful study of air compression, designed the compressors shown in Plate X, and they were built by the Fulton Engineering and Ship-Building Company of San Francisco. They are made very heavy, to stand the high piston speed required by the conditions of the water power. Had it been known at the time of designing this plant that a wheel could have been made like the one described, a diameter of 30 ft. instead of 18 ft. would have been chosen and the piston speed of the compressors reduced accordingly, for there is no question but that 60 to 70 revolutions will do better work than 110. The compressor cylinders are 18 and 10 ins. in diameter and 24 ins. stroke, with a water jacket so arranged that two streams of water pass around the cylinders in opposite directions. The inlet valves are of the Brenner pattern and open directly into the power room. Mechanical valves and air inlets from the wheel pit were considered, but taking into consideration the class of mechanics likely to handle the machine, and its remoteness from the shops, it was decided to adopt the simplest valves and place them so as to be reached easily. The compressor cylinders were made sufficiently large to allow for the rarefaction of the air caused by the automatic valve, and all the air that enters the building is forced to come up through the wheel pit. The other valves are made after the pattern of ammonia compressors.

The most novel feature of these machines is the intercooler. This is made up of 49 soft copper pipes, 1 in. in diameter, 18 ft. long, each with a stuffing-box at each end connected with manifold castings. The air delivered from the first cylinder into one manifold passes through these pipes to the other manifold, from which it is taken to the second cylinder. The whole is placed in the wheel pit directly under and in front of the wheel, so that the water dashes all over and through it. The air leaving the first cylinder at a temperature of 200° Fahr., passes through the intercooler and enters the second cylinder at 60°, slightly cooler than when entering the first cylinder. The temperature is again raised to 204° on leaving the second cylinder and passing into the transmission pipe, showing a total rise in temperature of 282° Fahr.

The transmission pipe, conducting the air at 90 to 100 lbs. pressure about 800 ft. from the compressors to works at the mine, is ordinarily

well tubing 5¾ ins. in diameter inside, screwed together in the trench and bent to fit the uneven ground by building fires around it and heating it until its own weight shaped it to the surface. After being laid and covered, it was tested by filling it with water under 120 lbs. pressure, which was allowed to stand over night. No leakage was discovered and none has appeared since. As yet only half of the full load of air has been passed through this pipe, so no data of value regarding loss in transmission through pipes have been obtained. With the present load the difference in pressure between the power house and the mine is not sufficient to be detected on the ordinary pressure gauge. At the mine there is the ordinary air receiver and also three 50 H. P. boilers set ready for steam, which are used for receivers.

The air is taken from these into the reheaters designed by Mr. Rix and built by the Fulton Company. As these are the first of their kind, it may be said they have proved remarkably well designed for their work. Experience has shown, however, that slight improvements can be made which would save fuel. At present it requires a little over half a cord of good pine wood each 24 hours to heat about 700 cu. ft. of free air per minute to a temperature 350 to 400° Fahr.

The heated air passes through pipes covered with magnesia and hair-felt to the first cylinder of the hoisting engine, from which it is exhausted back into the upper heater, where its temperature is again brought to 350°, whence it passes to the second cylinder at 30 lbs. pressure. From this it is exhausted through a flue to the change house, where it is used for heating and drying clothes. From the first heater also the air for the pump is conveyed some 300 ft. down the shaft in a similarly covered pipe. The pump was designed and built by Mr. George E. Dow, of San Francisco, and is a tandem compound vertical sinking pump of a capacity of 500 galls. 300 ft. high per minute. It receives the air at about 275° and exhausts it into the shaft at about 60°, thus giving plenty of pure cool air to the men, without the usual fans or ventilators. At the present writing, this pump is throwing 600 galls. per minute 240 ft. high.

In addition there is a direct-acting donkey pump throwing 350 galls. 110 ft. high situated in another shaft 750 ft. distant, to which air is carried cold in a 2-in. pipe over the surface. An old hot-water heater is used as a reheater for the air, and consumes 12 sticks of pine cord wood per 24 hours.

The hoisting engine is a compound direct-acting Corliss of 100 H. P. with cylinders jacketed for hot air, and is calculated to work 3 000 ft. down an incline of about 35 degrees. This was also designed by Mr. Rix and built by the Fulton Company. While it is especially adapted to the use of heated air, it takes steam as well as any engine and in fact was first tested with steam.

Efficiencies.—Efficiencies often seem to depend largely on the personal equation of the reporter. Mr. Rix's summary of tests is given in Appendix No. 2. He spent a number of weeks making them, and while agreeing with him in the main, the following are submitted as the author's conclusions. In any case, the plain tale is this. There is 304 theoretical H. P. in the water used at the power house, the work actually accomplished at the mine amounts to 203 H. P., and the cost of reheating is $3 per day.

Efficiency of compression and transmission from water wheel to motors, and not including cost of reheating............... $\frac{225.32}{283} = 79.5$ per cent.

Efficiency of compression and transmission from theoretical power of the water to the motors, and not including cost of reheating: $\frac{225.32}{304} = 74$ per cent.

Efficiency from the water wheel to and through the motors, not including reheating...... $\frac{202.7}{283} = 71.6$ per cent.

Efficiency from the theoretical power of the water, to and through the motors, and not including the cost of reheating.......... $\frac{202.7}{304} = 66$ per cent.

Efficiency of compression and transmission from water wheel to motors, including the cost of reheating expressed in water power: $\frac{225.32}{307.66} = 73$ per cent.

Efficiency of compression and transmission from the theoretical power of the water to the motors, including the cost of reheating expressed in water power................ $\frac{225.32}{329} = 68.4$ per cent.

Efficiency of compression and transmission from the water wheel to and through motors, including cost of reheating expressed in water power........................ $\frac{202.7}{307.66} = 65.5$ per cent.

Efficiency of compression and transmission from the theoretical power of water to and through the motors, including cost of reheating expressed in water power....... $\frac{202.7}{329} = 61.6$ per cent.

Horse power of air at works after reheating: 225.32.

Horse power delivered to compressors by water wheel: 283.

Theoretical horse power of water used on the wheel: 304.

Horse power of work actually done by the motors: 202.7.

The horse power delivered by the water wheel to the compressor, to which is added the horse power (24.66) which the cost of the wood used in reheating would buy in water: $307.66 = 283 + 24.66$.

The theoretical horse power of the water used on wheel added to the horse power (24.66) which the cost of the wood used in reheating would buy in water: $329 = 304 + 24.66$.

After nearly three months' working of the plant, the author believes the results obtained demonstrate the wisdom of having chosen air instead of electricity.

It may be urged that the conditions are particularly favorable to compressed air, as the transmission is short and the power is not needed for tramways or lighting. For lighting it is admitted without question, and possibly for tramways, that electricity is preferable, but for transmission, were it 20 miles instead of 1 000 feet, it is thought by the author that, taking the whole plant, compressor, transmission pipe and motor, as against generator, transmission wires, transformers, and electric motors, the air will prove cheaper in first cost, higher in efficiency, less liable to accident, and less expensive to operate and maintain.

The sense of being solidly supported in his plans and expenditures and encouraged to make his work thorough by the money power behind him is so rare in the experience of the American engineer as to be worthy of grateful mention; but still more rarely does he find, united to this material backing, the moral support which comes of the comprehension and sympathy of a wise engineer. This was the great good fortune of the author in carrying out the decision in favor of compressed air transmission and other somewhat novel features of the plant, under the sanction of Mr. James D. Hague, the President of the North Star Mining Company.

APPENDIX No. 1.

THE PROBLEM OF THE WHEEL.

By E. S. Cobb, Esq.

The problem is to design a wheel, the total weight of which is to be 10 000 lbs., as nearly as possible, the diameter 18 ft. 4 ins., the rim of suitable section to receive the buckets of a Pelton water wheel, and the whole strong enough to be in continuous use at 110 revolutions per minute while transmitting 226 H. P. from rim to shaft.

The cross-section of rim adopted is shown in Fig. 2. It is made up as follows:

Two 6 × 4 × ⅝-in. angles, weighing 20 lbs. per foot, 40 lbs. per foot of rim.

Four 4 × 4 × ⅝-in. angles, weighing 15½ lbs. per foot, 62 lbs. per foot of rim.

Center plate ¾ in. thick, 28 lbs. per foot of rim.

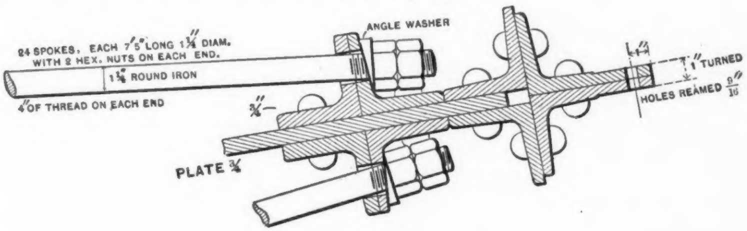

Fig. 2.

The mean diameter of the rim is 16 ft., and the average weight per foot is 135.2 lbs., including rivet heads. The total weight of the rim is 6 800 lbs.

The rim is held concentric with the shaft by twelve pairs of radial spokes. Strictly speaking, however, these spokes are at a slight angle with the plane of revolution, and this angle is taken into account in the calculations.

For the purpose of determining the maximum strain in working that may be expected by one pair of spokes, the rim is assumed to be cut into twelve pieces, each piece weighing 575 lbs., and being held in position against centrifugal force by one pair of spokes. Then the strain on each pair of radial spokes due to the velocity is found as follows:

Centrifugal force $= \dfrac{\text{weight} \times \text{radius} \times \text{rev.}^2}{2\ 936}$. Substituting the proper quantities $\dfrac{575 \times 8 \times 12\ 100}{2\ 936} = 18\ 958$ lbs., or 9 479 lbs. per spoke.

By reason of the position of the spoke at an angle with the plane of revolution, this strain becomes 10 000 lbs. per spoke. As $1\frac{1}{4}$-in. round iron is used, there is at the bottom of threads a safe area of 0.7854 sq. in., or a strain of 12 700 lbs. per square inch of section, on the assumption that these rods hold the whole of the centrifugal force acting in the rim, without any aid from the strength of the rim itself.

The strain at the least cross-section of the rim when it sustains its own centrifugal force without any aid from the radial spokes is as follows:

$$\frac{135.2 \times 8 \times 12\,100}{2\,936} = 4\,458 \text{ lbs.}$$

nearly, per foot of diameter. At 16 ft. average diameter, the total bursting strain of 71 328 lbs. is held by two sections, or 35 664 lbs.

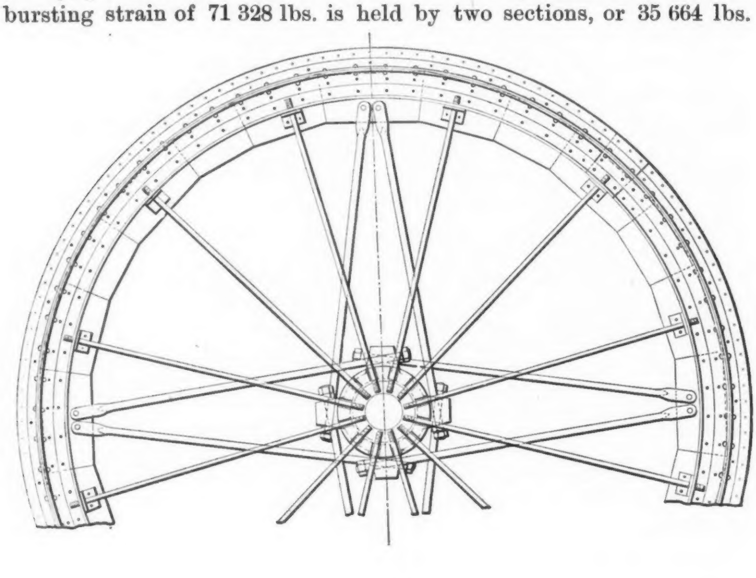

FIG. 3.

per least cross-section. The least cross-section of the rim is the section of the six angle irons, or 30.6 sq. ins. Deducting 25% for unknown imperfections and rivet holes leaves about 23 sq. ins. area, giving a strain of 1 550 lbs. per square inch of rim, when it alone is sustaining all the strain due to centrifugal force.

Power being applied to rim to develop 226 H. P. at 110 revolutions per minute, there results as the tangential strain at the ends of the truss rods 1 500 lbs., or 375 lbs. tangential strain at the end of each truss rod. This tangential strain produces in the rod, on account of its position, a tensile strain of 2 207 lbs., or 1 100 lbs. per square inch of net cross-section when seven threads are allowed for.

The general form of the wheel is shown in Fig. 3.

APPENDIX No. 2.

SUMMARY OF TESTS OF THE NORTH STAR POWER AND TRANSMISSION PLANT.

By E. A. Rix, Esq.

Actual capacity of compressor, 1 412 cu. ft. of free air compressed to 90 lbs. gauge.

Volumetric efficiency, 96.6% determined as follows:

Barometer pressure, 13.42. At 90 lbs. gauge, compression ratio is $103.42 \div 13.42 = 7.7$. Receiver, air pipe, and all storage, reduced to 90 lbs. gauge, contained 291 cu. ft., which equals 2 240 cu. ft. of free air. Compressor averaged 102½ revolutions to fill this at 90 lbs. from 25 lbs., which was intercooler pressure. Receiver, etc., at 25 lbs. gauge contained 830 cu. ft. free air. $2\,240 - 830 = 1\,410$ cu. ft. delivered by 102½ revolutions; deducting 2% for increase of temperature in receiver makes 1 382 cu. ft. at 60°, the outside temperature. Theoretical capacity of compressor, 1 429 cu. ft. at 102½ revolutions, $1\,382 \div 1\,429 = 96.6$ volumetric efficiency. Reduced to 110 revolutions, this gives 1 412 cu. ft. working capacity. To compress this, 304 theoretical H. P. of water was used on 18-ft. 6-in. Pelton wheel, at 110 revolutions.

The indicated horse power in all the cylinders averaged 250 H. P., and friction load 22 H. P.; total, 272 H. P. $272 \div 304 = 90\%$ efficiency for water wheel.

This friction load was determined when machine had no pressure on it, but was running at normal speed. Experiments on steam compressors show that the friction load is 50% more under full work. This would, then, be $22 + 11 = 33$ H. P. friction load, making total of $272 + 11$, or 283 H. P. delivered by wheel, or $283 \div 304 = 93\%$ of theoretical power in water.

The head of water is 730 ft. on the wheel.

The work of compression and delivery is $250 \div 304 = 82.2\%$ of the theoretical horse power, or $250 \div 283 = 88.3\%$ of horse power delivered by wheel.

The 1 412 cu. ft. of air is reheated to 350° Fahr., and, considering that it is used in a compound Corliss engine with intermediate reheating, the theoretical potential in the air before use is 225.32 H. P., determined as follows:

The cylinders being jacketed for hot air the Y which is used in calculations is the same as that used for compound, jacketed compression, viz., 1.3; then

$$Y = 1.3; \quad Y - 1 = 0.3; \quad \frac{Y-1}{Y} = 0.23; \frac{Y}{Y-1} = 4.33.$$

Barometric pressure = 13.42. Outside temperature, 60° Fahr.

The work being equally distributed between the two cylinders, the intermediate pressure will be the mean proportional between the initial and final pressures. Initial pressure, $90 + 13.42 = 103.42$. Final pressure, $13.42 + 1 = 14.42$ (1 being the exhaust pressure above atmosphere). Then $\sqrt{103.42 \times 14.42} = 38.62$, absolute intermediate pressure. The formula for the work in the cylinders will then be:

$$\frac{\frac{Y}{Y-1} P\, V \frac{T_3}{T} \left(1 - \frac{p_2}{p_1}\right) \left(\frac{Y-1}{Y}\right)}{33\,000}$$

in which the elements are

$$\frac{Y}{Y-1} = 4.33$$

P = barometric pressure per square foot $= 13.42 \times 144$.
V = cubic feet free air.
T_3 = temperature of reheating, absolute $= 461 + 350 = 811$.
T = absolute outside temperature $= 461 + 60 = 521$.
p_2 = intermediate pressure $= 38.62$.
p_1 = initial pressure $= 103.42$, and

$$\frac{Y-1}{Y} = 0.23.$$

Then substituting the equation becomes:

$$\frac{4.33 \times 13.42 \times 144 \times 1\,412 \times \frac{811}{521}\left(1 - \frac{38.62}{103.42}\right) 0.23.}{33\,000.}$$

Or $554.96 \times 0.203 = 112.66$ H. P. in one cylinder, or 225.32 H. P. in two cylinders.

Inasmuch as $3 worth of wood, or its equivalent, 15 ins. of water at 20 cents an inch, has to be added for reheating, the following allowance must be made for this: 15 ins. of water under 730 ft. head equals 30 H. P. The work of compression and delivery being 82% of the theoretical horse power, 30×82.2, or 24.66, represents the actual value of power delivered to the air to account for reheating, then, $250 + 24.66 = 274.66$ is the total power spent on the air. It has a theoretical potential of 225.32 and consequently $225.32 \div 274.66 = 82$ per cent. Counting from the theoretical power in the water, the efficiency would be $225 \div 304 = 74$ per cent.

This 82% represents the efficiency of the compressed air system under unfavorable circumstances. It was deemed advisable to have the water wheel on the compressor shaft, and 18½ ft. was the limit of diameter which could be contracted for. This made a revolution speed of 110, and a piston speed of 440, which reached 660 ft. at the half stroke just when discharge was beginning from the cylinders. These piston speeds are too high for economical work. Running the water wheel throttled at 80 revolutions, or a piston speed of 320 ft., the indicator cards showed a horse power of 247, including the friction load. This

would show an efficiency of $225.32 \div 247 = 90\%$, or from the theoretical water power $225 \div 275 = 80\%$, and were the same plant to be built again this could easily be attained, because it has been ascertained from the experience with the present water wheel that its diameter can be increased so as to run at 80 revolutions.

What power value will be in this 90% efficiency will depend largely on the motors used. The theoretical potential was calculated on the assumption that compound Corliss, jacketed, double-reheated engines should be used. Allowing that these engines have a mechanical efficiency of 90%, which is not a high efficiency, the horse power realized will be 90×90, or 81% of the indicated horse power of the compressors, or $90 \times 80 = 72\%$ of the theoretical value of the water power. With other classes of motors, the value of their work can be proportioned to the above percentages directly as their economic value is to that of the compound Corliss motor from which the air potential was assumed.

When the pump was first started it made 71 strokes, theoretically 710 galls., or 5 893 lbs. The pump has a volumetric efficiency of 95%, which would make this quantity 839 752 foot-pounds. This was done with the compressor running at 80, and the air pressure at 90. At the present time, the pump is making 60 strokes or 4 980 lbs., pumping 230 ft., making 1 145 400 foot-pounds, or, at 95% volumetric efficiency, 1 088 130 foot-pounds. This is being done with 93 single revolutions, at 90 lbs.

The compressor is making 90 single revolutions at an average of 92½ lbs. pressure, which is equivalent to 93 single revolutions at 90 lbs., in order to reduce both the performances to the same pressure.

The difference between the foot-pounds of work in both of these cases, viz., 1 088 130 — 839 752 is 248 378 foot-pounds. The difference in revolutions is 13; consequently 13 revolutions did 248 378 foot-pounds of work, or 19 100 foot-pounds for one single revolution.

It is evident that this work is what the pump is capable of doing, independent of its friction of pipes, etc., because the friction of the pump and the friction of the pipes within the small working limits of this pump are practically the same, as will be seen from the following: For 93 single revolutions, were there no friction of pipes or inertia of pump to overcome, it is evident the pump should perform 93 times 19 100 foot-pounds of work, or 1 776 300 foot-pounds. It really did 1 088 130 foot-pounds, the difference being 688 170 foot-pounds, which is the friction of the pipes and inertia losses.

In the other case 80 revolutions should have done 80 times 19 100, or 1 528 000. It actually did 839 752, the difference being 688 248, again almost identical with the first proposition. So the mean between these two, or 688 209 foot-pounds, is the actual pump loss, and this loss it would seem is almost the same at any head within the working limits of the pump.

The loss now being determined, it is possible to determine what actual work is being done, and if the pump efficiency is determined, a check can be made on the potential of the compressor.

If at 93 revolutions the pump does 1 088 130 foot-pounds of work, and the friction is 688 248 foot-pounds, and 19 100 foot-pounds are added for each single revolution of the compressor up to its limit of speed, viz., 220 single revolutions, this last amount being 2 425 700 foot-pounds, there would result a total of 4 202 078 foot-pounds of work which the pump would do when the compressor is running its 220 single revolutions, or its limit. If there is deducted from this amount the friction and inertia loss of 688 248 foot-pounds, the result is 3 513 830 foot-pounds, which is the usual effort of the pump, and the ratio between what the pump actually does and the foot-pounds of work it consumes, would be its efficiency, which, upon dividing these sums by each other, shows the mechanical efficiency of the pump to be 83 per cent.

If the potential of the compressor is 225.32 H. P. and the efficiency of the typical motor is 90%, then the brake horse power possible for the typical motor would be 225.32 times 0.9, or 202.7 H. P. for 220 single revolutions of the compressor. For one revolution it would be 0.992, which is 30 426 foot-pounds.

The pump actually does 19 100 foot-pounds for one revolution. The ratio therefore between 19 100 which the pump actually does, and 30 426 which the typical motor would be capable of, would be the pump efficiency as compared to that of the motor. This would be 62 per cent. This includes temperature, the friction in pipes and inertia losses between the reheater and the pump exhaust.

Inasmuch as the pump did 4 202 076 foot-pounds of work with an efficiency of 62%, as compared to the typical motor, the typical motor would yield 4 202 076 ÷ 0.62 = 6 600 000 foot-pounds, or 200 H. P., which compares very favorably with the original calculations for the brake horse power at the potential as being 202.7.

Recapitulating these figures:

The total work done by the pump	=	4 202 076	foot-pounds.
The total brake horse power of the ideal motor	=	6 600 000	"
The total potential of the air after reheating	=	7 434 900	"
The total work spent on the air, including the energy of reheating at 440 ft. piston speed........	=	9 042 000	"
The total work spent on the air, including the energy of reheating at 320 ft. piston speed	=	8 215 000	"
Theoretical power of the water at 440 ft. piston speed	=	10 032 000	"

Theoretical power of the water at 320 ft. piston speed........................	= 9 205 000 foot-pounds.
Total power of the water, including the energy of reheating at 440 ft. piston speed............................	= 10 692 000 "
Total power of the water, including the energy of reheating at 320 ft. piston speed............................	= 9 865 000 "

Under the lower piston speed, which should be the proper speed to run the compressor, the ratio of original power and reheating, 9 860 000 foot-pounds, and the total pump result, 4 202 000 foot-pounds, would be 44%, which would be the efficiency from first to last as far as the pump system was concerned, and the ratio between any other of the elements in the preceding recapitulation will be their relative percentages.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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PAPERS.

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THE CONDITION OF STEEL IN BRIDGE PINS.

By A. C. CUNNINGHAM, M. Am. Soc. C. E.

TO BE PRESENTED AT THE ANNUAL CONVENTION, 1896.

The engineer who receives a report of a large number of tests from plates, angles and other shapes used in his bridge, which indicates an excellent material, may naturally suppose that his bridge pins, made under the same specification, and perhaps from the same casts of steel, are of the same excellent quality. That such is not the case will be demonstrated.

A few years ago it was customary to accept bridge pins, and also other material, on the result of a test made on a specially rolled ¾-in. round rod. The apparent simplicity and convenience of this method of testing was what led to its adoption, but it did not take long to demonstrate its inconvenience, and the fact that the steel was often in finished shapes before the test rod were rolled. This resulted in the substitution of tests from the finished material, with or without the round tests as a matter of record, and this substitution soon dem-

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onstrated that a small round test was not an accurate indication of the condition of steel in other shapes.

Very naturally this replacement of round tests by tests from finished material led engineers to ask for tests from finished pins, but such requests did not meet with encouragement from manufacturers, who opposed them on the grounds of expense and time. The engineer finally prevailed, however, and pins began to be tested, with results startling to some and disagreeable to others. The test from finished pins is now an established, though not a popular, custom.

Bridge pins are of two general classes, rolled and forged, and the change from one class to the other takes place at a diameter of about 6 ins. An ingot is rolled down to a bloom of convenient size, and this bloom is rolled or forged to the size ordered.

In the case of rolled pins the main consideration of the roller is to finish the pin truly round and of the required diameter and not break his rolls. This last consideration leads him to have the bloom heated as hot as may be without burning, and in consequence it happens frequently that some blooms are too hot and are burnt or overheated. Six-inch pins are often finished so hot that a bar 25 ft. long can be cut into 18-in. lengths on the hot saw. It will be seen from this that heat treatment and finishing temperature are refinements which stop short of rolled pins. These are generally made from the smallest blooms that are suited to the rolls and will finish to given diameters, and are finished very hot. In consequence, they lack work, both in reduction of section and finishing temperature, and are likely to be coarsely crystalline and deficient in toughness and ductility, if not absolutely brittle; see Tables Nos. 2 and 3.

The main reason for changing from rolled to forged pins at a diameter of about 6 ins. is a practical one. Existing rolls will not make a much larger size, and in the lengths in which they are rolled, they become difficult to handle. In making forged pins, the size of bloom is again the important consideration for the manufacturer. It must not be too large for the hammerman to handle conveniently in the heating furnace or under the hammer, and the result is that many so-called forged pins are little more than blooms with the corners knocked down. The weight, power and size of the hammer used for making forged pins have an important bearing on their final condition. For a small hammer a small bloom must be used, and it must

be made very hot. The blow from the small hammer on a large bloom is merely a surface blow, the work of which does not penetrate the metal to any extent.

With small hammers and large pins there is, then, a highly heated bloom, the shape of which is changed to a round by sliding the exterior over the interior without working the latter, and with the result of frequently rupturing the interior portions, especially if the bloom is not uniformly heated. The larger the hammer used for making forged pins, the better will be the results; larger blooms can be used, the work of the blow will penetrate deeper, they can be forged at a lower heat, and some attention can be given to the finishing temperature.

When pins first began to be tested, it was quickly discovered that the test nearest to the surface of the pin gave the best results, and that there was a constant falling off of quality as the test approached the center. It was also discovered that the size and shape of the test piece affected the results. Of two test pieces cut near the surface of a pin, one ¾ in. in diameter, and the other 1 in., the former will give the better results, and a flat, thin test piece in the line of a chord will give better results than either of the round pieces.

The most marked difference between the tests from pins and tests from shapes or plates is in the reduction of area and the appearance of the fracture. While the test piece from the surface of a pin may give a fair reduction of area with a fine, silky fracture, as the center is approached the reduction becomes decidedly less, and the fracture grows more coarse, irregular and cokey, until it may finally terminate with a crystalline fracture and little or no reduction. This change of appearance and loss of reduction indicates lack of work, too much heat, or both.

When pins are tested strictly with a view to ascertaining their quality, and not for the purpose of getting them past a specification, it is found that forged pins are better than rolled pins, and that the better the steel, the better the resulting pin, other conditions being the same. It is also found that a medium hard steel of about 70 000 lbs. ultimate strength will give better results than a soft steel. All pins are also improved by annealing.

From a consideration of Table No. 1, Cast A, it will be seen that even with an excellent quality of uniform steel, there is a falling off

of ultimate strength and physical properties as the center is approached. This may be ascribed to a lack of work and a high finishing temperature. Table No. 1, Cast B, shows the possibility of having highly segregated steel in a pin. In this pin the phosphorus and sulphur have doubled from the outside to the center, and from an excellent quality of steel the metal changes to a very ordinary quality. Had the cast analysis of this steel shown only an ordinary quality to start with, the steel at the center of this pin would have been dangerously defective.

Table No. 2 shows the generally poor results in a rolled pin made from common steel, and how the test may be improved by annealing. It may fairly be assumed that the pins themselves would also be improved by annealing. In this table, as in some of the others, there is what appears to be a paradox, namely, a rise in ultimate strength after annealing. This is undoubtedly due to a release of initial stress in the original pin by the annealing. A rise of ultimate strength, and an improvement of elongation, reduction and appearance of fracture after annealing are not confined to pin tests; the same phenomena are observed in eye-bars and other heavy sections. The initial stress may be readily caused by uneven heating or cooling.

Table No. 3 shows how un-uniform and treacherous it is possible for rolled pins to be. This steel is of a common quality, and not by any means as poor as much that is made. The analyses from the broken end indicate that it was approaching the zone of maximum segregation, but stopped short of it. From this table the improvement due to annealing may be again seen.

Table No. 4 shows the improvement in physical properties due to annealing the test piece, and, also, to even a crude annealing of the pin itself. It also shows that a good analysis does not alone insure good results. The blooms from which these pins were forged were so small that they received but little work, and were finished at a high heat.

From the foregoing it may be seen that bridge pins, even when made from a superior quality of steel, are not in a uniform condition; that the interior portions show a lack of work, and may show excessive segregation, which in steel of common quality is liable to reach a dangerous amount; it is also shown that pins are improved by annealing.

The following specification is submitted as being likely to procure as good bridge pins as can be had in common practice:

Bridge pins shall be made of open-hearth steel.

If made of acid steel, the cast analysis shall show not more than 0.06% of phosphorus, nor more than 0.03% of sulphur. If made of basic steel the cast analysis shall show not more than 0.03% of phosphorus, nor more than 0.03% of sulphur.

The manganese for either steel shall be not less than 0.5%, nor more than 0.8 per cent.

The smallest diameter of the final bloom or ingot to be made into pins shall be at least 50% greater than the diameter of the pin.

All pins shall be stamped with the cast number of the steel from which they are made, and shall be stamped with consecutive numbers from the bottom of the ingot to the top.

After pins have been manufactured to diameter, they shall be slowly and uniformly heated to a dark red heat in a suitable furnace, and left to cool slowly for a period of not less than 24 hours.

Tests cut from near the surface of annealed pins, and of a sectional area of not less than ½ sq. in. shall have an ultimate strength of not less than 60 000, nor more than 70 000 lbs., per square inch, an elastic limit of not less than one-half the ultimate strength, an elongation in 8 ins. of not less than 20%, and a reduction of area at fracture of not less than 40 per cent.

Tests cut from near the center of pins shall comply with the above requirements, except that a fall of 5 000 lbs. in ultimate strength, and a fall of 5% in reduction of area, will be allowed.

The fractures of all pin tests shall be free from granulation.

Analysis of drillings taken from near the surface of pins shall not exceed the limits of the cast analysis by more than 10%, and, when taken from near the center, shall not exceed said limits by more than 50 per cent.

Tests and analyses shall be made on such pins as the engineer shall designate.

TABLE No. 1.—Tests from Acid Open-Hearth Steel Pins.

Nomenclature for Fractures.—C., Cup; Ck., Cokey; Cr., Crystalline; I., Irregular; S., Silky.

Cast.	Chemical Test. Percentage of elements. C.	P.	Mn.	S.	Test From	Physical Test. Stress, pounds per square inch. Elastic.	Ultimate.	Percentage of strain. Elongation in 8 ins.	Reduction in area.	Nature of fracture.
A	.22	.051	.39	.031	Cast analysis..	....	....	......	......	.. ..
"	.22	.049	.39	.030	10-in. forged pin No. 1.	37 780	62 550	20.7	50.0	Ck. ½C.
"	.22	.050	.40	.031	" " " No. 2.	37 800	58 780	19.2	43.0	" "
"	.28	.053	.39	.035	" " " No. 3.	36 570	56 140	22.5	37.7	" I.
B	.22	.053	.40	.038	Cast analysis........	....	....	......	......	....
"	.24	.053	.44	.033	8-in. forged pin No. 1.	39 820	60 640	20.2	52.9	S. I.
"	.28	.062	.45	.039	" " " No 2.	41 700	66 200	18.7	38.7	Ck. I.
"	.38	.105	.47	.078	" " " No. 3.	41 100	74 360	10.0	11.2	Cr.

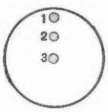


Diagram of relative position of test pieces in pins. Pieces were turned to ¾ in. diameter, and drillings for analysis were taken from them after breaking. Tests A were all from the same pin, and tests B were all from a second pin.

TABLE No. 2.—Tests of Acid Bessemer Steel Pins.

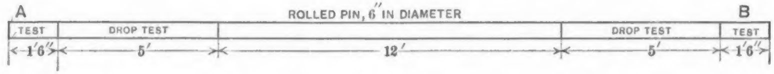
Nomenclature for Fractures.—C., Cup; Gr., Granular; S., Silky.

Cast.	Test From	Physical Test. Stress. Pounds per square inch. Elastic.	Ultimate.	Percentage of strain. Elongation in 8 ins.	Reduction of area.	Nature of fracture.	Remarks.
A.....	6¾" rolled pin.	36 510	62 910	20.0	17.7	Gr.	Not treated.
".....	" "	37 960	58 320	24.0	59.4	S. A.	Annealed in lime.
B.....	6⅝" "	37 800	60 320	13.2	11.3	Gr.	Not treated.
".....	" "	38 080	60 250	28.0	61.1	S. ½ C.	Annealed in lime.
C.....	" "	38 100	57 480	8.7	15.0	Gr.	Not treated.
".....	" "	41 180	62 800	26.2	62.2	S. C.	Annealed in lime.
D	" "	38 900	53 120	8.0	8.7	Gr.	Not treated.
".....	" "	39 190	62 160	26.0	59.3	S. A.	Annealed in lime.

The above pins were made from an ordinary quality of steel, the chemical composition of which is unknown.

The first test in each group was cut from the pin as it was finished at the rolls; the second test was cut from the same pin and annealed in lime. The appearance of the fractures of annealed test pieces was excellent.

TABLE No. 3.—Tests of Acid Bessemer Steel Pin.



Nomenclature for Fractures.—A., Angular; C., Cup; Cs., Coarse; Fi., Fine; Gr., Granular; I., Irregular; S., Silky.

Chemical Test.				Test From	Physical Test.					Remarks.
Percentage of elements.					Stress. Pounds per square inch.		Percentage of strain.		Nature of fracture.	
C.	P.	Mn.	S.		Elastic.	Ultimate.	Elongation in 8 ins.	Reduction of area.		
.11	.103	.60	.061	End B, No. 1..................	39 710	62 780	27.0	38.8	S. ½ C.	Annealed in lime.
.11	.117	.60	.062	2	38 450	63 540	25.5	40.3	S. I.	" " "
.11	.110	.56	.060	(c) 3..................	35 020	59 460	13.8	12.2	Gr.	Not treated.
.10	.106	.61	.058	4..................	35 500	62 500	15.3	13.4	"	" "
.11	.120	.60	.062	(e) 5..................	32 850	56 400	11.3	8.8	"	" "
.10	.106	.62	.057	End A, No. 1..................	41 000	60 100	30.0	65.7	S. ¾ C.	Annealed in lime.
.10	.100	.60	.055	2..................	40 110	59 330	30.0	66.8	S. ½ C.	" " "
.10	.104	.59	.055	3..................	31 520	56 350	29.5	49.3	Cs. Ck. I.	Not treated.
.10	.107	.60	.057	4..................	33 160	57 360	28.0	42.0	" " "	" "
.10	.114	.60	.055	5..................	29 840	55 300	30.0	45 5	" " "	" "

Above tests were 1 in. diameter.

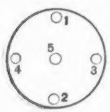
BROKEN TESTS *c* AND *e* FORGED TO ¾-IN. SQUARES.

.11 .11	.110 .120	.56 .60	.06 .062	End B, No. 3.............. 5.................	43 680 45 600	67 040 67 440	18.7 21.2	33.8 40.7	Fi. S. A. Fi. S T.	Tests not annealed, but left with hammer temper.

DROP TESTS.—WEIGHT OF DROP, 1 640 LBS ; SUPPORTS, 3 FT. APART; TEST PIECE REVERSED AFTER EACH BLOW.

	END A.				END B.			
Number of blow..............	1	2	3	4	1	2	3	4
Fall....	25 ft.	25 ft.	25 ft.	25 ft.	15 ft.	20 ft.	25 ft.	29 ft.
Deflection...........................	2 ins.	⅛ in.	2 ins.	Broken.	1⅛ ins.	¾ in.	1½ ins.	Broken.

The 6 in. round was rolled from an 8½ x 8½-in. bloom, which was rolled from a 15 x 18-in. ingot. The round had a short curve in the end B where the bar had followed the roll. An attempt was made to straighten this in a gag press, and at the first blow of the plunger the bar broke short off 1 ft. 6 ins. from the end B.



The position of the test pieces in relation to each other and to the pin is shown in the diagram. The analyses were made from drillings taken from the broken test pieces.

TABLE No. 4.—TESTS FROM BASIC OPEN-HEARTH PINS.

Nomenclature for Fractures.—A., Angular; C., Cup; Ck., Cokey; Gr., Granular; S., Silky.

CAST.	CHEMICAL TESTS. Percentage of elements.			TEST FROM	PHYSICAL TEST. Stress, pounds per square inch.		Percentage of strain.		Nature of Fracture.	REMARKS.	
	C.	P.	Mn.		Elastic.	Ultimate.	Elongation in 8 ins.	Reduction of area.			Size of test.
A	.29	.031	.63	6¼-in. forged pin.	37 620	67 840	25.0	36.7	Ck. C	Not treated...............	⅞ in. diameter.
"	Cast a	nalys	is	" " ..	40 640	67 300	18.0	30.2	" ½ C.	"	1⅛ in. "
"	......	......	......	" " ..	40 000	72 200	18.0	28.4	Gr.	"	2 x ½ in.
"	......	.....	......	" " ..	36 760	68 520	22.7	49.0	S. ½ C.	Annealed in lime........	⅞ in. diameter.
The above tests all from the same pin, forged from an 8½ x 8½-in. bloom.											
B	.29	.032	.52	6¼-in forged pin...	39 510	67 350	20.0	30.0	50% Gr.	Not treated..............	1 in. diameter.
"	Cast a	nalys	is ...	" " ..	35 790	64 620	28.2	49.9	S. ¾ C.	Annealed in sand........	1⅛ in. "
"	......	......	......	" " ..	39 530	66 150	26.2	41.9	S. A	" "	" "
C	.29	.032	.53	6¼-in. forged pin..	39 220	68 560	20.0	27.7	75% Gr.	Not treated..............	1 in. "
"	Cast a	nalys	is	" " ..	38 160	65 270	26.5	43.6	S. A.	Annealed in sand........	1⅛ in. "
"	......	......	......	" " ..	39 490	66 280	26.5	48.0	S. ¾C.	" "	" "

Tests marked, "not treated," were cut from pins as finished by the hammer. In casts B and C, the second and third tests in each group were cut from pins which, after being forged, were reheated to a red heat and buried in dry sand for 24 hours.

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PAPERS.

THE CONSTRUCTION OF A LIGHT MOUNTAIN RAILROAD IN THE REPUBLIC OF COLOMBIA.

By E. J. CHIBAS, Assoc. M. Am. Soc. C. E.

TO BE PRESENTED AT THE ANNUAL CONVENTION, 1896.

In the construction of a railroad in a country where sufficient traffic is already in existence to warrant a fair return on the contemplated investment and where capital can be easily procured, the main object should be to build the road with such light curves and grades that the operating expenses may be kept down to the lowest limit, almost regardless of first cost, as long as the interest on the additional capital required does not exceed the saving that will be effected in the operating expenses by the additional outlay, as in that manner the line will be in a condition to face active competition. On the other hand, where a railroad has to be built in a new and undeveloped country to accommodate a light traffic which is not expected to increase materially for many years to come, and where capital is limited, it becomes necessary to adopt sharper curves and heavier gradients than customary, if, by so doing, the first cost of construction can be decreased to such an amount as to make possible an enterprise of otherwise

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prohibitory cost. The purpose of this paper is to describe a railroad of this nature, built for the Caribbean Manganese Company of Baltimore, Md., in the Department of Panama, Republic of Colombia. The main line of the road at present in operation is 9 miles long and extends from the harbor of Nombre de Dios to the Nispero and Soledad manganese mines. The Nombre de Dios Harbor is on the Caribbean Sea, about 40 miles northeast of Colon.

During the spring of 1892 the author was requested to make preliminary surveys and estimates for a railroad from the mines which had recently been discovered, to the nearest and most appropriate place on the coast available for shipping purposes. An examination of the coast showed that there were only two places to be considered, Viento Frio and Nombre de Dios, the former being 5 miles east of the latter. Both were inhabited by a few native villagers whose only communication with the outside world was by means of their canoes, as there was no vessel running to either locality, except an occasional trading schooner which would stop far from shore and take in a small load of cocoanuts or ivory nuts. No plans or chart of that portion of the coast having ever been made, approximate hydrographic surveys of both harbors were made to determine their future possibilities as shipping ports. The investigation revealed that Nombre de Dios would make a fairly good port, while Viento Frio could not be used at all unless a large amount of coral rock was blasted and dredged.

A general exploration or reconnaissance of the country lying between the mines and the two ports was then made, which was a very difficult undertaking, as the country was covered with a dense forest or thick undergrowth, the larger portion of which had never been penetrated, except, perhaps, by a few natives. There were no roads and very few footpaths. The investigations had to be carried on generally by wading and following up the streams and creeks, by ascending to the top of adjacent hills or climbing trees at convenient localities from which to ascertain the topography of the surrounding country. It was finally decided that the most economical route for the railroad would be the one following the general direction of the Viento Frio River, as it was discovered that between the mines and the sea there are ranges of hills running parallel to the coast which only appeared to flatten out when they approached the narrow valley formed by the Viento Frio River.

Preliminary lines were then run from Nombre de Dios and Viento Frio to Nispero along the general route selected by the reconnaissance. The progress of this survey was very slow, as it depended almost entirely on the progress made by the natives in cutting out the line with their machetes through the thick undergrowth. The average progress varied from 2 000 to 4 000 ft. per day. Topography was taken on both sides of the line, covering a belt of country from 200 to 500 ft. in width. The whole line was afterward plotted on a scale of 400 ft. to the inch. The line from Viento Frio to Nispero turned out to be 6¼ miles long, and the one from Nombre de Dios 8½ miles. The former was the shorter and cheaper line, but the saving in its cost was far from compensating for the large expenditure which would have to be made to improve the Viento Frio harbor. For that reason the author, in his report made to the company in July, 1892, advised against the construction of that line, and, after weighing all considerations, recommended the construction of the railroad from Nombre de Dios as the more economical line.

During the latter part of December of the same year he was asked to take charge of the work to be carried out in Colombia, and was informed at the same time that there had been many difficulties in obtaining the right-of-way to Nombre de Dios, so the company was forced to build the railroad to Viento Frio. As no improvements in the harbor were contemplated, the ships would have to anchor outside and receive their cargoes by lighters. During some portions of the year this was possible, as the dead calm prevailing in that latitude made the sea very smooth, but at other times the prevailing trade winds made the sea so rough that it would have been impossible to ship at all. For this reason it was decided to send only a few shipments from Viento Frio, in the hope that the right-of-way matter would be settled in the meanwhile, and then proceed to Nombre de Dios.

During the latter portion of 1892 Mr. E. G. Williams had been sent by the company to make surveys from Viento Frio to Nispero along more direct routes; but his estimates proved that any such routes would cost twice as much as the one proposed by the author.

The location of the railroad was therefore made along the Viento Frio River route, and it was started during the first week of February, 1893. The average rate was in the neighborhood of a quarter of a mile per day. Although the plans of the original preliminary

were carried in the field for constant consultation, no attempt was made to follow the paper location. Maximum curves of 40°, 146 ft. radius, and maximum grades of 5% in favor of traffic, were adopted, so as to reduce to a minimum the amount of excavations to be made. The only adverse grades were some short ones of 1 and 1½ per cent. As it was only in the last mile that the natural level of the country rose very rapidly, it was possible to concentrate all the heavy grades in that portion of the line, which made operating very convenient, as by placing a switch at the foot of the grade the locomotive can haul to it a large number of empty cars and from there to the mines make as many trips as the number of sections into which it is found necessary to divide the train.

The country being broken by a large number of gulches and creeks, a corresponding number of small bridges was required to cross them. All the drainage of the portion of the country under consideration is carried to the sea through the Viento Frio River. This has a very moderate velocity in ordinary stages and is only from 40 to 80 ft. in width, but during the rainy season and in time of flood, like most of the tropical streams, carries a large volume of water with a corresponding increase in velocity. The located line crossed this river twice, and its tributary, the Mamey, four times. In all these cases it was found cheaper to bridge across than to keep on the same side, as either the increase in the length of the line resulting from following the windings of the stream or the increase in excavation due to the much rougher mountain side would have added considerably to the expense of construction. In locating the line along the side hills it was fitted as close as possible to the natural formation of the ground, and it was placed in cuttings so that the whole road-bed would rest on solid ground, as no embankment could have stood on the steep side hills, washed at the bottom by a stream that would carry away any embankment not formed of broken rock which would come within the limits of its high-water mark.

After the location was completed the older estimate was revised and a new and careful estimate was made of the cost of constructing the railroad from Viento Frio to Nispero, including the equipment necessary to begin operations at the mines, as well as the lighters required at the port for shipping the ore. This estimate had to be approved by the Board of Directors of the company in Baltimore before any

work of construction could be started, but while waiting for further orders, the clearing and grubbing of the line was executed and work suspended in May. Construction was finally started in January, 1894. It was found that the right-of-way which had been cleared and grubbed seven months previous was covered with luxuriant vegetation, attaining in places heights of 5 to 7 ft. Some of the center stakes furnished proof of the extreme vitality of the vegetation in that portion of the tropics, as they seemed to have been imbued with new life and were covered with green leaves.

After the clearing had been performed several places were found in going over the line, as is usually the case, where improvements could be made in the alignment, and changes were made accordingly, although not as many as desirable, because the work of grading was pushed so rapidly as to give the engineering corps no time for making minor changes. The last mile, however, comprising the most difficult portion of the work, was gone over. The previous work was platted to a scale of 100 ft. to the inch. A new location was made on paper, and trial lines following the paper location closely though not exactly were afterward run on the ground until the result was as satisfactory as the nature of the country would allow.

It was believed that the cargo of material, comprising rails and fittings for 6¼ miles of track, timber, cars, a locomotive and other items, would arrive about May 1st at Viento Frio, but various causes delayed the accumulation of sufficient rails and timber to begin work until about August 1st, when track-laying and bridge-building were started.

The bridgework was a source of considerable trouble, as the chief carpenter expected from the United States never arrived. None of the so-called carpenters engaged in the neighborhood could understand or work from plans, and their workmanship was so poor that, even after laying out the whole work for them, they had to be watched closely to keep them from spoiling the timber. It was not until after half of the work had been accomplished in this manner that a few fairly good carpenters were secured; the work then proceeded at a better rate and with little interruption.

Owing to these difficulties, it soon became evident that the first shipment of ore could not be sent from Viento Frio about the middle of September, as had been expected, and if the shipping was delayed

much longer, the season would be so far advanced that the risks of loading vessels at this port would be considerably increased. In the meanwhile the relations between the company and the owners of the land around Nombre de Dios had become more cordial, and finally satisfactory arrangements were concluded for the right-of-way. This did away with the necessity of shipping from Viento Frio, and it was decided to extend the line to Nombre de Dios. The distance from this port to the nearest point on the line of the completed railroad was 4 miles. The location was started from that point, which was 1½ miles from Viento Frio. For the first mile the line skirts the flanks of the mountain to escape crossing a swamp which extends from its foot to the coast. From the beginning of the second mile to Nombre de Dios the line is built wholly on embankments, as the mountains recede from the coast, leaving a wide plain between them and the sea, which is covered by lagoons and swamps narrowing considerably as they approach the coast. For this reason the line was located closer to the coast than to the mountains, and it was possible to employ easy curves and long tangents. The ground close to the line was considerably improved afterward by drainage ditches. The location and some of the clearing were performed during the worst part of the rainy season, and a large portion of the plain was covered ankle deep with water. It was considered unadvisable for hygienic reasons to commence grading before the rainy season was nearly over, or about January 1st, 1895.

The material for the extension arrived in Nombre de Dios by schooner on March 1st.

The first train of manganese ore from the mines to Nombre de Dios was run about April 20th, and three weeks later the steamship *Earnwell*, the first steamer ever seen in Nombre de Dios Harbor, came in and took away the first cargo of ore. Later on, the railroad was extended half a mile more from Nispero to Soledad.

Clearing.—The clearing and grubbing of the road from Viento Frio to Nispero cost $360 per mile. The forest and undergrowth were very heavy. The view shown in Plate XI, Fig. 1, was taken while the clearing was going on. As the general direction of this line was north and south, the clearing was made wide enough to allow the sun's rays to penetrate during a large part of the day, and in that manner contribute to the quick drying of the roadbed. The average width was about

100 ft., 50 ft. on each side of the center line; but on steep side hills the clearing was carried on the upper slope to 75 ft., and at times 100 ft. or more from the center line, so as to prevent trees from falling down to the track after the road was in operation. In spite of this care nearly a year after a certain portion of the line had been completed, and shortly after the author returned to the United States, he was informed that a tree which had been left standing about 200 ft. from the track and was thought to be at a safe distance away, was undermined by very heavy rains, came down the side hill at a rapid rate and damaged the track and the end of a trestle. This instance is given to show that in countries where excessive rains cause rapid erosion, not much reliance can be placed on the apparent stability of trees on side hills, and the clearing on the upper portion of the slope cannot be made too wide to secure absolute immunity from trouble caused by falling trees.

The clearing and grubbing of the Nombre de Dios branch cost $197 per mile. The cost was less than that of the former line, because, the general direction of the line being east and west, the clearing was not made so wide. The average was about 60 ft. Moreover, portions of the ground had been under cultivation and the clearing was not so heavy as in the former line.

The whole line was divided into small sections which were given by contract to one or more laborers. The prices varied according to the nature of the vegetation to be removed and were below what similar portions had cost in the former clearing, which had been done by the day. This work was mostly done by natives, as they are superior to the Jamaica negroes for labor of this nature, where axes and machetes are the only tools required.

It was difficult to get the natives to take the contract for clearing a portion of the line where manzanilla, a very poisonous tree, was abundant, but those who finally did the work proved that their fears were not entirely unfounded as some of them were afterward confined for several days with a mild attack of blood poisoning, their faces becoming so swollen that it was difficult to see their eyes.*

* This seems to be produced by the sap coming in contact with any portions of the skin. Its principle antidote is sea water, which is fortunate, in that the tree only flourishes along the coast line, at least in the portion of the country referred to in this paper. The method generally pursued by the natives for getting rid of these trees is to build a fire around them, and after they are partially burned allow them to dry out, although in the construction of the railroad time could not be spared for the completion of the latter operation. The tree bears a fruit resembling a very small apple, which is also poisonous.

Earthwork.—The total amount of material handled in the 10½ miles of road graded was 94 670 cu. yds., most of which was tough clay. The approximate classification of the material encountered was about as follows: 67% of tough clay; 20% of earth or heavy soil; 11% of shale and decomposed rock, and 1% of hard rock, which was chiefly confined to the last mile. The cost, regardless of classification, was 20 cents per cubic yard, including the cost of tools and explosives and the drainage ditches along the whole line of the railroad. About 64 670 cu. yds. was taken from cuts, and 30 000 cu. yds. was used in embankments. Nearly all the latter being light, but few attempts were made to balance the cuts and fills, as it was thought cheaper in this case to waste in cuts and borrow from the sides for the fills. The deepest center cut was 35 ft., but as most of the cutting was on steep side hills, much lighter cuts made the upper slope stakes reach heights of from 50 to 70 ft. above the grade line. All the light work was given out by contract in small sections, varying from 100 to 1 000 ft. in length, to one or more laborers. To avoid disputes the prices were not given per cubic yard, as few of the men had any idea of what that measure represented. The contents in each section was calculated by the engineers and the prices were given for each separate section without stating its contents. Center stakes were placed every 50 ft., and on the sharp curves every 25 ft. Slope stakes were placed to correspond with each center stake. The prices varied from 12 cents per cubic yard for low fills made by shoveling from the sides to 16 cents per cubic yard for tough clay in the cuts and higher embankments. All the heavy work was done by the day, except such portions as could be conveniently given by the piece. Whenever it was possible to give out any work by the piece, that system was preferred, as it invariably proved cheaper and quicker than day work. For some time after the first small contracts were given out, whether for clearing, grading, felling and hauling timber, hewing or any other work, a record was kept of the number of men and the time employed in carrying them out, so as to determine the wages they were making and find if the unit price was susceptible of still further reduction. In this manner a large portion of the work was carried out more cheaply than would have been possible by day labor.

In pick and shovel work, and, in fact, in nearly all manual labor except clearing and seamanship, the Jamaica negroes proved superior

to the natives. Their pay in ordinary work was about $1 or $1.20 per day of the silver currency of the country, which at that time was equivalent to nearly 50 and 60 cents American currency respectively. Their efficiency as compared with American labor is in nearly the same proportion as their respective rates of pay. Under good discipline they are easily managed, and on account of their partial immunity from the unhealthy effects of the climate they are valuable aids to any enterprises in this portion of the tropics.

The embankments were made only wide enough to allow the track to be laid on them, or from 7 to 8 ft. It was expected to make them wider after the completion of the road, and while shipments of ore were going on, because the traffic being very light it would allow the train crew plenty of time to haul the refuse from the mines and dump it over the embankments. In this manner, while the cost of construction was decreased slightly, the cost of operation would not be very much affected. In ordinary cases, however, the author would not recommend the building of embankments less than 10 ft. wide for a 3-ft. gauge road, particularly where the rainfall is heavy, as what is saved in dirt will be lost in ballast where sufficient room is not left between the ties and the edge of the embankments. The cuts were made 10 ft. wide. This is the least dimension which it is advisable to adopt, so as to allow room for the water to run off, and 12 ft. would be much better. Several slides occurred in some of the cuts after completion, but they were not as many as had been anticipated from the heavy rainfall.

Bridges.—There were 2 489 lin. ft. of bridges built; 2 093 ft. were pile trestles, and 396 ft. were framed trestles resting on mud sills, and varying in height to 30 ft. In length they varied from 15 to 120 ft., except the pile trestle built to the ore dump at the port, which measured 285 ft. The total amount of lumber consumed was 121 800 ft. B. M., exclusive of piles, which numbered 374, and added 6 600 lin. ft. Of the lumber 43 500 ft. was Georgia pine shipped from Baltimore, and 78 300 ft. was native timber. The former cost from $40 to $45 per thousand feet, after paying freight, unloading and transportation to site. The cost of felling, hewing and hauling to site the native timber varied from $15 to $35 per thousand feet, depending on the distance and nature of country through which it had to be hauled.

The piles were all of native timber, and were delivered in place for 9 cents per lineal foot, which made the cost of the average pile about $2 20. The average penetration varied from 8 to 12 ft. Nearly all the piles were driven before the arrival of the track material by means of a light pile-driver with a 1 000-lb. hammer and a hand winch. The pile-driver was transported on a cart from site to site on the completed road-bed, and the cost of driving the piles of the first six miles, from Viento Frio to Nispero was $5 95 per pile, including the cost of the pile-driver and cart. During the construction of the 4-mile branch to Nombre de Dios, a modification was made in the system of transporting the driver which proved very satisfactory. Instead of a cart, a portable track and cars, which had been bought for use at the mines, were utilized. This track of 20-in. gauge came in sections about 15 ft. long, which were easily carried by two men. About 300 ft. were laid on the roadbed, and four of the small mining cars transformed into platform cars were placed on this track. On the first two the driver was loaded and pushed to the end of the track. The other two cars were kept in the rear to carry the rails, which were taken up as the pile-driver advanced. As soon as they came close to the latter, the rails were taken from the rear cars and laid ahead. The process was repeated until the driver reached the desired point. In this manner progress was more rapid and not interrupted by the mud formed by heavy rains. The cost of driving the piles in this case was $4 80 per pile. The decrease in the cost was not only due to the change in the system of transporting the driver, but also to the increased efficiency of the labor by their former experience and better average weather. It is not believed that the result would have been more economical had steam been used as motive power, considering the increased difficulty in moving the driver along the newly made embankments, and the higher wages which it would have been necessary to pay for skilled labor. Had the piles been more numerous, and a larger number of them in each bridge, the increase in speed resulting from the use of an engine would have warranted the expense, but as the pile-driver followed the grading gang, and most of the piles were driven before the other bridge material arrived, nothing would have been gained by the use of a steam engine.

The average cost of the completed trestles, including all material

and labor, was $4 20 per running foot. They were designed for the use of 15-ton locomotives.

The pile bents were composed of two or three piles according to their height, braced laterally by 2 x 12-in. planks. Posts, sills and mud sills of framed trestles were 10 x 10 ins.; caps 10 x 12 ins. and 8 or 9 ft. long. Stringers, when of native timber, for 15-ft. spans were made of 12 x 14-in. single sticks under each rail; for 20-ft. spans they were 15 x 18 ins., although both sections were increased whenever the size of the timber from which they were hewn made it possible to do so. The bolts and drift bolts used were $\frac{3}{4}$ and $\frac{5}{8}$ in. in diameter. The framed trestles were braced laterally by 2 x 12-in. pine, and longitudinally by 5 x 8-in. pine sticks. The two inner posts were made plumb, and the two outer posts were given a batter of 3 ins. to the foot, except in the trestle on the 40° curve, where the post on the outer side of the curve was given a batter of 4 ins. to the foot. In the case of some of the bents on a steep rocky bottom, instead of leveling this off, as would have been required had a sill been used, it was found cheaper to locate the places where the posts would strike the rock, and, after drilling and blasting four holes about 18 ins. deep, and from 18 to 24 ft. in diameter, the posts were placed in them and the vacant spaces filled with cement. About 500 ft. of bridges are on curves. One pile trestle 110 ft. long and 13 ft. high, and one framed trestle 80 ft. long and 22 ft. high, are on a 40° curve. In both cases the stringers used are of pine, bent to form the curve. Before starting this operation the bents must be thoroughly braced, as otherwise the elasticity of the timber will tend to displace them. In this pile trestle the spans are 15 ft., and the stringers are made up of three 6 x 12-in. sticks 30 ft. long under each rail and breaking joints. In the framed structure the spans were only 12 ft., and the stringers were composed of two 6 x 12-in. pieces 24 ft. long, placed under each rail and breaking joints.

The superelevation of the outer rail in curves was calculated for low speeds; the maximum adopted was 4 ins. for the 40° curve. The difference in elevation was generally made up in the posts, except when the superelevation was under $1\frac{1}{2}$ ins., when the lower rail was dropped that amount by hewing down the tie. The rails used for inner guard rails were of the same section as those in the main track.

The pile trestles built across the Viento Frio and its tributary, the

Mamey, have stood without accidents the successive floods of two rainy seasons. The spans in these cases were made 20 ft. wide, and as no longitudinal braces were employed and the three piles in each bent were driven parallel to the current, they offer the least surface of resistance to the flow of water in time of flood. The great danger lies in the amount of drift wood generally carried down, as shown in Plate XI, Fig. 2. This view was taken after a flood, when the drift which had accumulated against bridge No. 31 was being removed. This is the pile trestle on the 40° curve already described, the outside of the curve being toward the up-stream side. This makes the trestle act like an arch to resist the thrust of the drift, which is particularly likely to be stopped here because the spans were reduced to 15 ft. on account of the sharpness of the curve. The bridge was not damaged, but about 20 ft. of the embankment shown in the view was washed away. This happened during the first rainy season after the construction of the road had been started, when there were many logs and pieces of wood from the clearing which were not dry enough to burn and found their way to the streams during the first floods. The first and second rainy seasons having taken away most of this wood, it is not likely that any of the bridges will be submitted to the same strain in the future, and with a little watching to prevent accumulation of the drift wood there seems to be no reason for entertaining any fear on that source.

Colombian Timber.—Very little is known as to the durability of the native timber in the Department of Panama, as on account of the lack of transportation facilities it has generally been found cheaper to use pine imported from the Southern States. It is known, however, that nispero, a very hard wood used extensively for house building many years ago, is still found in good condition in houses said to be nearly a century old. In all these cases the wood was in the interior and well painted and protected from sun and rain, but it is likely that the same wood exposed to the trying weather will last only a small fraction of that time, as the climatic conditions prevailing in the locality, that is, constant heat and excessive humidity, are the most unfavorable for the preservation of any class of timber. Creosoted pine timber has been used very extensively for engineering works in the Isthmus and will outlast considerably the untreated pine.

It is a prevalent opinion in tropical countries that the moon exerts much influence on the vegetation in those latitudes, and the best time

for felling timber is held to be during the six days preceding or following the last quarter of the moon. It is said that timber cut during the period extending from the new to the full moon is shown by repeated experience to become decayed or worm-eaten more quickly than any other, and some facts that came under the author's observation seem to verify the theory.*

Culverts.—Owing to the heavy rainfall, a large number of culverts had to be built. They were sometimes box culverts, made out of pine planks 3 ins. thick, but in many cases they were built of native logs, and made large enough to allow a box to be slipped in after the road was in operation, whenever inspection revealed the necessity of no longer relying on the native timber.

Track.—The rails weighed 35 lbs. per yard. The gauge of track was made 3 ft. Although the author fully appreciates the defects of the narrow gauge, he thinks there are many cases where it can be used to advantage. This is especially the case where no connection with a standard gauge road is expected, and where the first cost of construction has to be watched so closely that even small savings due to narrower road-beds, narrower bridges and shorter ties become of importance, while if the future traffic is expected to be light, the difference between the cost of operating a standard and a narrow-gauge road would be insignificant.

* The roofs of some of the construction camps and dwellings were made of palm leaves. Whenever they were cut during the first quarter of the moon, worms would soon attack them and in about four months they would become useless, while the same quality of palm cut during the last quarter of the moon would seem to resist the worms for a long while and would last about a year, or three times as long as the other. Again, while making the railroad surveys three camps were built along the line and the timber for posts and roofing was cut as required without regard to the condition of the moon. At the end of a year it had been badly eaten by worms. Later on it was necessary to build other camps in the neighborhood, and the same qualities of timber were used from the same locality, but cut during the last quarter of the moon. At the end of a year they had not been attacked by worms, nor showed any signs of decay. The natives seem to have such an implicit faith in this that they will always watch the faces of the moon before felling any timber for their own uses. Nearly all the tropical engineers of experience with whom the author has discussed the subject seem to substantiate the opinion held by the country people, and they make use of that clause in their specifications for native timber. It is possible that the time of greatest activity in the vegetation in the tropics takes place during the first quarter of the moon, and that the sap, being abundant and in rapid circulation, makes the timber unfit for felling; while during the last quarter of the moon the vegetation is probably at rest, making that time the most appropriate for felling. The author makes use of the expression in the tropics, because he does not know whether the fact, or what appears to be an unquestionable fact, has been observed in higher latitudes. If it has not, might it not be due to the greater difference in temperature between summer and winter, which has a tendency to make the periods of greatest activity and rest dependent on the seasons instead of on the much milder effects that the moon could exert? It would be interesting to know what observations have been made by other members of the profession on this matter.

About 2 200 ties to the mile were used, costing on an average 25 cents per tie; their dimensions were 6 x 6 ins. and 5 x 6 ins., by 6 ft. long, although some 5 x 5 ins. were also used. They were hewed out of the native timber in the neighborhood. Some of the ties were rotten within a year from the time they were laid and many more showed signs of decay, but the ties of nispero, sigua olorosa and carbonero seemed to have stood very well. For that reason these three woods, especially the first two, are being used exclusively for repairs, until a longer test can determine the length of their useful life. Some of the hard-wood ties have to be bored before they are spiked. The Panama Railroad, the only other railroad in the Department, uses at present only one class of ties. They are of lignum vitæ, from the valley of the Magdalena River, and are delivered to the Panama Railroad for $1 30, $1 50 and $1 80 per tie, according to their dimensions. The author was shown a portion of a lignum vitæ tie by the engineer of the Panama Railroad, who stated he had taken it from the road after it had been in use for 30 years. Although considerably worn out, it was in a fairly sound condition.

The track laying from Viento Frio to Nispero cost $250 per mile. The work was performed by an American foreman, and all the labor under him from spikers down were new to the work. The large number of small bridges, which prevented an early use of the track in the transportation of lumber, and the inefficiency of the carpenters first engaged, were causes of frequent interruptions to the track-laying gang. In laying the 4-mile branch to Nombre de Dios, where there were fewer bridges to cause interruption, and where the bridge gang, as well as the track-laying gang, had profited by the experience of the previous work, the cost was $200 per mile. It had been the intention to ballast the track only slightly, using as much as possible the material near the track for tamping purposes, and to leave the remaining work for future improvements. It soon became apparent, however, that on account of the excessive rains a larger amount of ballast would be required, and the quicker it was in place, the more satisfactory the result would be. Two cuts along the line of the road, the only ones available for the purpose, were turned into ballast pits, and the material was hauled from them and dumped all along the line. The material was a decomposed rock, requiring very little blasting to handle it, and made a very fair ballast. It was while this work was

going on that it was decided to extend the railroad to Nombre de Dios, but for reasons already stated it was not practicable to begin active work on that line until about January, 1895. It being inadvisable on account of the peculiar location of the work to discharge all the men, as it would have been difficult to find them when again wanted, as many men were employed on the track as was consistent with economy, and in that manner it was brought to a better standard than had been anticipated. This work cost $540 per mile. After completion the road required very little care for some time, and it was in better condition than many passenger roads in Spanish America. The ballasting of the Nombre de Dios branch cost $420 per mile.

Alignment.—As regards the alignment of the line at present in operation, of its total length of 47 048 ft., 17 935 ft. are curves. There being eighty-three of these, the average length is 216 ft. The total amount of curvature to the right is 1 794° 25′, or nearly 5 complete circles. The total amount to the left is 1 914° 57′, or about 5.3 complete circles. Therefore, the total amount of curvature, irrespective of direction, is 3 709° 22′, or about 10.3 complete circles. The longest curve is 847 ft.; it is a 5° curve, with a total angle of 42° 21′. The largest angle is 127° 36′, in a 40° curve, 319 ft. long. There are twenty 40° curves, eighteen 30°, nine between 30° and 20°, twelve 20°, twelve between 20° and 10°, eleven of 10°, and the remainder vary from 9 to 3 degrees. The average degree of curve over the whole of the curve portion of the line is 20 degrees. The longest tangent is 3 906 ft. In the first three miles of the road, starting from Nombre de Dios, there are, besides the tangent mentioned, one of 2 100 ft. and three of about 1 300 ft. In this portion of the line the curvature is very light, and only amounts to 265°, being mostly 5 and 6° curves, with the exception of two of 10°; but after passing the third mile, when the line gets among the hills, the number and the degrees of the curves begin to increase very rapidly. The alignment of the last portion of the railroad is shown in Fig. 1. To avoid confusion the degree of each curve only is shown, and the stations marked every 1 000 ft. The stations are numbered from Viento Frio, not from Nombre de Dios. The profile of the same portion, representing the heaviest work performed, is also shown in Fig. 1. The 5% grade to the Nispero terminal is compensated for curvature at the rate 0.03 ft. per degree of curve;

but owing to the small scale of the profile, only the line indicating the average grade of 4.55% is shown. For the last half mile the 5% grade is laid without compensation, which makes its resistance in the short 40° curve equivalent to that of a 6% grade. The trestles are marked *B*, and the culverts *C*, in the profile, Fig. 1.

Plate XII, Fig. 1, shows one of the side hill cuts in the Soledad extension. One of the mining cars used in grading is shown at work. The portion of the line shown on the left of the view is on a 40° curve. This cut furnishes a good illustration of the necessity of the sharp curves in following the sudden turns of the mountains. The Mamey flows at the foot of this hill, but is not shown in the view.

Climate.—Although Nombre de Dios is 9° 36′ north of the equator, the hottest isothermal line passes along that coast line. The average temperature ranges from 78 to 95 degrees. It seldom goes below the former or above the latter, and 86° can be taken as an average temperature. The humidity is always excessive, and according to observations made by the author with a hygrometer, it ranges from 75 to 94 per cent. The more common average varies from 85 to 90 per cent. The author kept a rain gauge at the coast, and the amount of rainfall was recorded every day at 6 A. M. and 6 P. M. The total for the year 1894 amounted to 127 ins. The heaviest rainfall was recorded in the month of December when 26 ins. fell. The maximum rainfall recorded in twelve hours was 6 ins. At the upper end of the railroad much more rain falls than at the coast, probably on account of the thicker and more abundant forest at that end, but no record was kept there. Judging, however, by comparison, the amount of rainfall must have been about 150 ins. during the same year.

There are only two seasons, the rainy and the dry. The former is the longest and extends from the last of April to about the first of January. During this long rainy season, however, there are irregular dry spells of several weeks at a time. On the Pacific slope the rainy season is generally shorter by one or two months.

As soon as the work of construction was started in January, 1894, precautions were taken against the fevers, which it was feared would develop as soon as deep excavations were made in the clay or the swamp work undertaken, particular care being taken about the drinking water, which was at times boiled and filtered. It was not until about May 1st or after nearly all the grading had been accomplished and the

PLATE XI.
PAPERS AM. SOC. C. E.
MAY, 1896.
CHIBAS ON CONSTRUCTION OF MOUNTAIN RAILROAD.

FIG. 1.

FIG. 2.

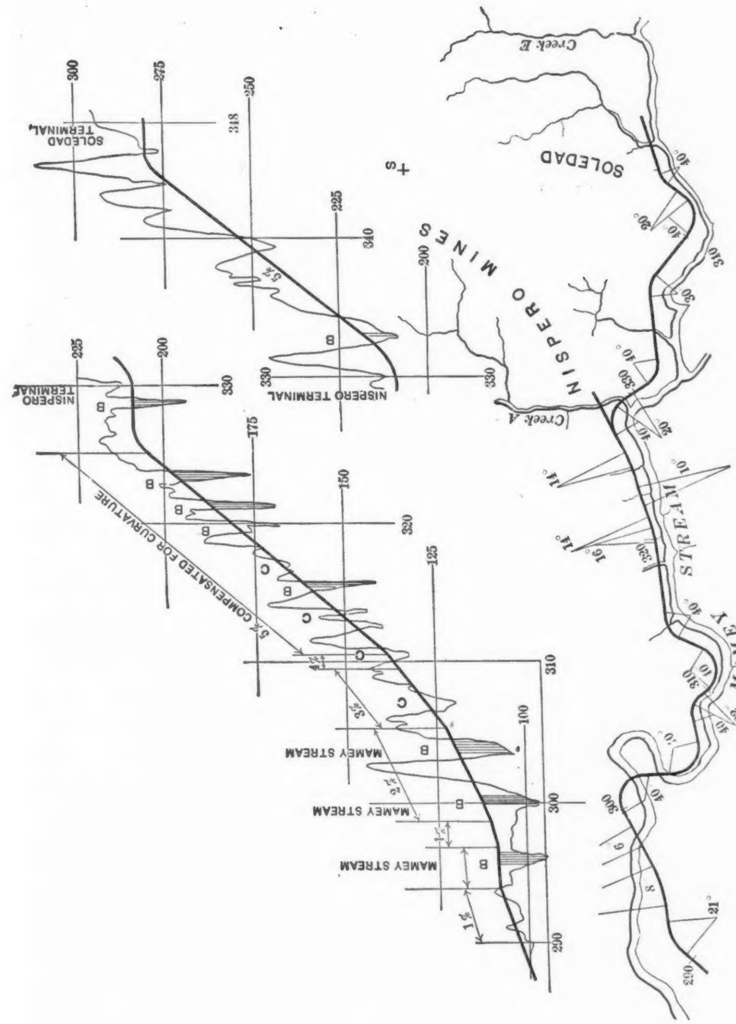
SOLEDAD TERMINAL
NISPERO TERMINAL
NISPERO TERMINAL
5% COMPENSATED FOR CURVATURE
MAMEY STREAM
MAMEY STREAM
MAMEY STREAM
NISPERO MINES
SOLEDAD
Creek E
Creek A
MAMEY STREAM

FIG. 1.

rainy season had settled in, that fevers began to spread, and a month later there was not an employee, native or foreign, who had escaped them. The Jamaica negroes suffered less from their effects than any of the other laborers. These fevers were of a paludal nature, and returned at intervals of four to five weeks, according to the individual. They did not assume a malignant nature and no fatalities resulted from them, but they were a source of considerable annoyance and directly or indirectly caused frequent interruptions in the work. Whenever work of this nature is performed in the tropics more or less fever is apt to develop; it cannot be avoided, but with good care and by the enforcement of sanitary regulations, it can be prevented from developing into a dangerous epidemic. This trying period only lasts during construction.

Handling Ore.—The main manganese ore deposit lies in the district enclosed by creeks *A* and *E*, Fig. 1. The former is in what is called the Nispero mine, and the latter in the Soledad. The distance between both creeks is about half a mile. From both the Nispero and Soledad terminals of the railroad the ground rises very rapidly toward the summit marked *S* in the plan. This point is about 2 000 ft. horizontally from the Nispero terminal of the railroad and 500 ft. above it. The flanks of the mountain are cut up by several narrow gulches and ravines. For the transportation of the ore to the railroad cars, iron side-dumping mining cars of about ½ cu. yd. capacity are used, running on light portable track. The first track laid started from the top of the ore pocket at the Nispero terminal of the railroad. It was built along the side hill with a light rising grade of from 1½ to 2%, so as to allow the loaded cars to go down almost by themselves and at the same time allow the empty cars to be pushed up without much exertion. Similar lines were graded and laid at vertical intervals of 25, 50 or more feet, as the distribution of the ore required them. Connecting all these lines there is an inclined gravity plane with a grade of 30%, and as the loaded car goes down, it pulls up the empty one. The mining cars are loaded at each different level and pushed to the inclined plane, where they are hooked to the end of the rope and let down to the lower level, when they are unhooked and pushed to the ore pocket and their contents dumped.

In several cases where bodies of ore prevented direct communication for some time between the side lines and the inclined plane, the

FIG. 1.

FIG. 2.

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cars, instead of going down the incline, dumped their contents into a chute with an inclination of 45° to allow the ore to roll down to the bottom, where by lowering the gate its contents dropped into the car standing at that lower level or into empty cars standing on the incline. This system has not been extended to more than 150 ft. above the Nispero railroad terminal, as the mining operations are confined to that belt, but the same general system could be extended to cover the whole deposit and by close attention to details the number of handlings of the ore could be reduced to a minimum. After the work becomes higher more economy in operation would probably result from using two self-dumping cars on the gravity incline and confining each car to its own level. The author believes that the use of a wire cable tramway in this case, beside involving a larger expenditure in first cost, would not offer any economy in operation, considering the wide belt over which the ore is spread.

The ore pockets at the Nispero terminal of the railroad hold about 75 tons of ore, and those at the Soledad terminal about 200 tons. The inclination given to the bottom of the ore pockets, floored with 3-in. planks, was 45°, as this was found to allow the ore to slide down without sticking to the plank. Both ore pockets are provided with enough chutes to allow four or five railroad cars to be loaded at once. Plate XII, Fig, 2, shows a portion of a train carrying 50 tons of manganese ore, coming down the 5% grade.

The natural conditions of Nombre de Dios Harbor were very favorable for building a wharf at a small expenditure, as the deep water coming very close to the shore, which is of coral formation, allows the construction of a wharf with its length parallel to the shore and from only 30 to 50 ft. wide. Its length is about 200 ft. The steamers can load at the wharf as much as they can carry on a 17-ft. draft, which generally varies from 1 300 to 1 800 tons. To send a larger cargo the remaining portion is lightered to the steamer, which must anchor about 1 500 ft. from the wharf. At the port terminal of the railroad the ore is dumped off the cars from a trestle 10 ft. high running nearly parallel with the wharf and about 100 ft. from it. The manganese is loaded in ore buckets carried on small car trucks which are pushed on rails to the side of the steamer, where she lifts them with her own winches. In this manner by using sixteen buckets, it was possible to handle 400 tons per day of 10 hours, by loading through

two hatches at the same time. By a few contemplated improvements the rate of loading per day could be increased.

The first locomotive in use was built by the Ryan-McDonald Manufacturing Company. It weighed 25 000 lbs., distributed over two pairs of driving wheels measuring 30 ins. in diameter. The cylinders were 10 ins. in diameter by 14-in. stroke. The wheel base was 5 ft. 3 ins. No difficulty was encountered in running around the sharp curves with this locomotive, and after a year of constant use it did not show any effects of hard usage. Many, but not all, the 40° curves are provided with inner guard rails.

Water is pumped to a water tank in the lower portion of the line by means of a Rider hot-air engine, which proved very serviceable, as there is no boiler to look after and it needs very little care and skill to run it. Both of these considerations are very important factors in those countries where skilled labor is difficult to find and comes very high. The pump in question has a capacity of 400 galls. an hour and has been in use for over a year and a half without giving any trouble.

Cost.—In giving the cost of the various items of the work already mentioned, no portion of the engineering or other general expenses were charged to them.

The average cost of the railroad constructed from Viento Frio to Nispero was $12 000 per mile, the average for the Nombre de Dios branch was $6 800 per mile, including the cost of the wharf, of buildings and dwellings erected at Nombre de Dios, and the improvements at the port terminal. The cost of the $10\frac{1}{2}$ miles of railroad built and equipped averaged $13 400 per mile. This included, beside the equipment of the railroad proper, thirty mining cars and $\frac{1}{2}$ mile of portable track for the mines, as well as some harbor equipment, such as four 30-ton coppered wooden lighters, two iron buoys, two hoisting engines and derricks for the wharf. The cost of the wharf, buildings, etc., is also included, as well as that of the ore bins, and in fact all expenses incurred, whether in South America or Baltimore, in placing the entire property in working order from the time the author was authorized to begin construction in January, 1894, to December, 1895.

The heaviest work, as well as the most expensive portion of the railroad, was the last half mile, which cost $9 000. The amount of material handled in the grading of this section was 22 000 cu. yds.

The actual cost of the railroad from Viento Frio to Nispero, includ-

ing equipment for railroad, mines and harbor, turned out to be only $1\frac{3}{4}\%$ greater than the estimates made by Mr. E. G. Williams and the author in the spring of 1893, to which reference has already been made. It is fair to state, however, that the unit prices did not agree. Some of the items, like grading, ties and bridge buildings, came out lower than had been estimated; but on the other hand, the general expenses and contingency accounts were higher. The excesses and deficiencies, however, more or less compensated each other, with the final result stated. Changes were also made in the work and equipment, but they compensated each other and had no effect on the final result.

In making estimates for work to be performed in the tropics it must be borne in mind that in starting enterprises in these countries many expenses have to be incurred that would be foreign to a similar enterprise in the United States. It is true that labor is generally cheaper per day, but not so in view of the amount of work it accomplishes, with few exceptions in some particular lines which do not count for much in the long run. A doctor must be kept on the ground. The hospital account must be considered as well as its indirect effect in contributing to lengthen out the work and decreasing the value of physical exertion. Due allowances must be made for the transportation of the material to the nearest port and also for local transportation, which is generally very poor. There are also many other minor considerations inherent to all new enterprises in a new country, which, if not fully provided for, will overrun the estimated contingency account.

The author is pleased to acknowledge the valuable co-operation of the engineers associated with him in this work. He has already mentioned the connection of Mr. E. G. Williams with the early stages of the work, with whose able co-operation the first location of the railroad from Viento Frio was made. For all the work performed and described in this paper from the time construction was inaugurated, the writer is indebted to Messrs. R. M. Arango and C. C. Arosemena. Both were connected with the company from January, 1894, the former having been Principal Assistant Engineer to January, 1895, and the latter from that date to July of the same year.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

IMPROVING THE ENTRANCE TO A BAR HARBOR BY A SINGLE JETTY.

By T. W. SYMONS, M. Am. Soc. C. E.

TO BE PRESENTED AT THE ANNUAL CONVENTION, 1896.

In devising plans for the improvement of the entrances to the tidal harbors of the United States, the general system adopted has been to confine the outflowing and inflowing waters between parallel or converging jetties so located and arranged as to direct the waters upon the bar in a fixed position. Where single jetties have been planned, as at the mouth of the Columbia and San Diego, it has been because the other jetty was replaced by headland or permanent shore. The author's experience in charge of the improvement of a number of harbors on the Pacific Coast has convinced him that there are places where the double jetties are unnecessary and where a single jetty, if properly placed, will, in conjunction with natural tendencies, compel the entrance channel to adopt a fixed and permanent location and practically accomplish all that could be expected of two jetties, and at half, and sometimes less than half, the necessary cost of a pair.

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

Having to prepare plans for the improvement of the entrance to Grays Harbor in the State of Washington, he became satisfied from a study of the situation, the currents, the tides, the volume of flowing water and the channel movements, that here was a place where a single jetty was applicable. The improvement of the harbor was so planned, and the plan is presented to the Society in this paper, with the facts and reasons which led him to adopt it.

General Description.—It is considered a matter of importance if in certain places it is reasonable to expect to effect a marked and permanent improvement in a harbor entrance by a single jetty. There are places where improvement is greatly needed, but where the cost of double jetties would be prohibitory, but which could well stand the expense of a single jetty. It is a satisfaction in making a plan for a single jetty to know that if it be unsuccessful, it will form an essential part of a system of double jetties or other combination of structures necessary to secure the requisite control of the flowing waters.

The entrance to Grays Harbor from the Pacific Ocean lies in latitude 46° 55′ north, being 45 miles north of the mouth of the Columbia River.

The harbor has a length from east to west of 17 miles, and from north to south a maximum breadth of 14 miles. There are a number of rivers tributary to the harbor, the principal being the Chehalis, Satsop, Wynooche, Wishkah, Hoquiam and Humptulips, all of which come from the east and north, and drain one of the richest and most magnificently timbered sections of the State of Washington. There are two main channels crossing the harbor from east to west, of which the north channel is the principal one and the one undergoing improvement at its upper end. A large part of the harbor is occupied by tide flats, bare at low water. The total tidal area of the harbor is 96.8 square miles. At low tide the area covered by water is 30.6 square miles, or less than one-third of the total area. The average range of the tide is 8.4 ft., with a maximum range of 12.9 ft. The low area consists of a number of channels running through and between mud and sand flats. The banks of these channels are quite steep, so that the water does not begin to overflow the flats until it has risen about 2 ft. above mean low water. At about 5.2 ft. above mean low water, the flats are completely covered. Between this stage and mean high water, there is no considerable increase in water area.

From the data available, it is estimated that the volume of water displaced during a mean tide of 8.4 ft. is 16 000 000 000 cu. ft. Assuming the tide to run out for six hours, this gives an outflow of 748 000 cu. ft. per second. The volume of water displaced during a maximum tide amounts to 24 000 000 000 cu. ft., which, assuming the run-out to last six hours, makes a discharge of about 1 100 000 cu. ft. per second.

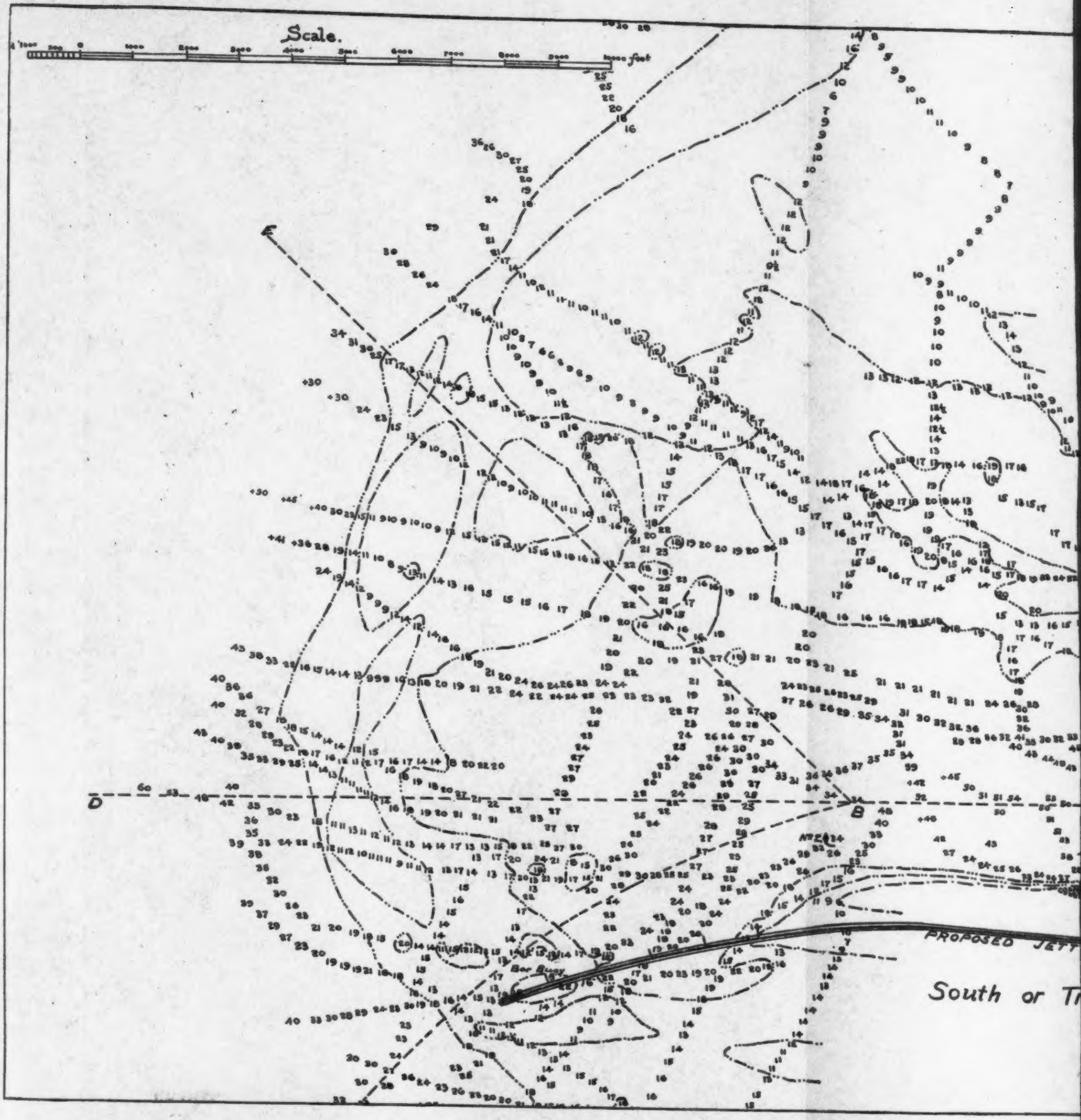
The harbor throat lies between two low, sandy peninsulas terminating on the north of the entrance at Point Brown, and on the south at Point Hanson. The distance between high-water lines on these two points is 12 500 ft. The survey of Grays Harbor entrance was made in October, 1894. The results of the survey are shown on the accompanying map, Plate XIII, upon which is indicated the location of the jetty proposed for the improvement of the harbor entrance. The soundings on the map are in feet, and are referred to the mean of the lower low waters.

The survey shows maximum depths of 100 ft. in the harbor throat. A single broad waterway extends for more than 2 miles from the harbor throat out to sea, with depths gradually diminishing from 100 ft. to 30 ft. Between this deep waterway and the open sea lies the usual bar, convex to the sea, and connected with the spits which jut out from Points Brown and Hanson. The spit from Point Brown is the North Spit, and that from Point Hanson is South or Trustee Spit. Across this bar there is no well-defined, decided, permanent channel. The best water was found at the time of the survey to be in a line southwesterly from Buoy No. 2. This was the channel used by tugs and boats entering the harbor, and was marked by a mid-channel buoy. The survey shows that fully as good a channel existed to the east of this, running more nearly due south. There is also shown nearly as good a channel to the northwest, and also a fairly good one nearly due west.

The governing depth on the bar in the south and southwest channels shown was 13 ft. at mean lower low water. In the northwest channel it was 12 ft.

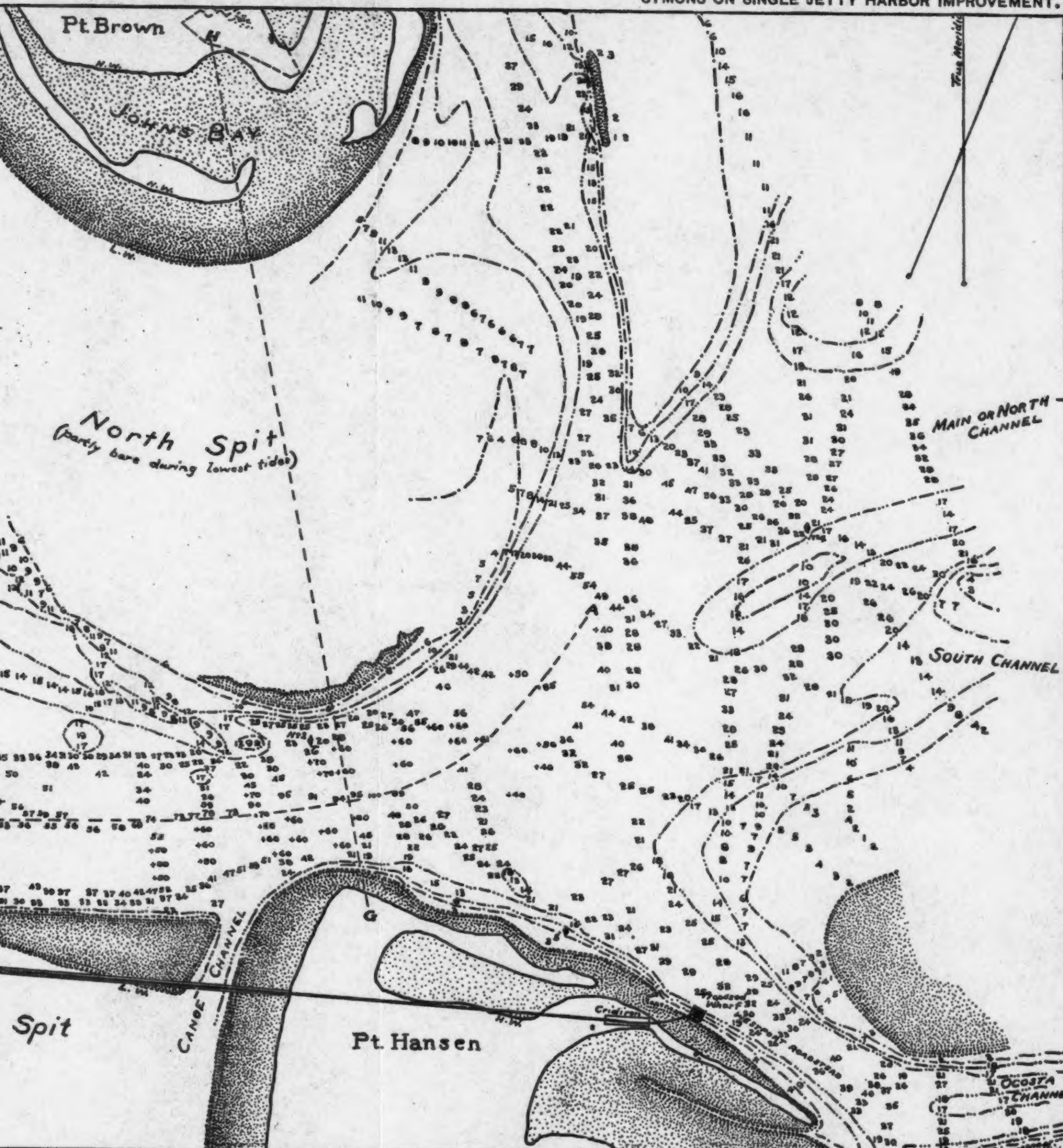
The general average distance between the inner and outer 18-ft. curves is ½ mile. The region between the two curves was found to be irregular, with lumps and depressions.

On the north of the entrance the extreme limit of Point Brown is a ribbon of sand partially encircling the main higher land, and separated


Scale.
feet
E
D
B
Bar Buoy
PROPOSED JETT
South or Tr


Pt. Brown
PROPOSED JETTY
South or Trustee Spit

PLATE XIII.
PAPERS AM. SOC. C. E.
MAY, 1896.
SYMONS ON SINGLE JETTY HARBOR IMPROVEMENT.



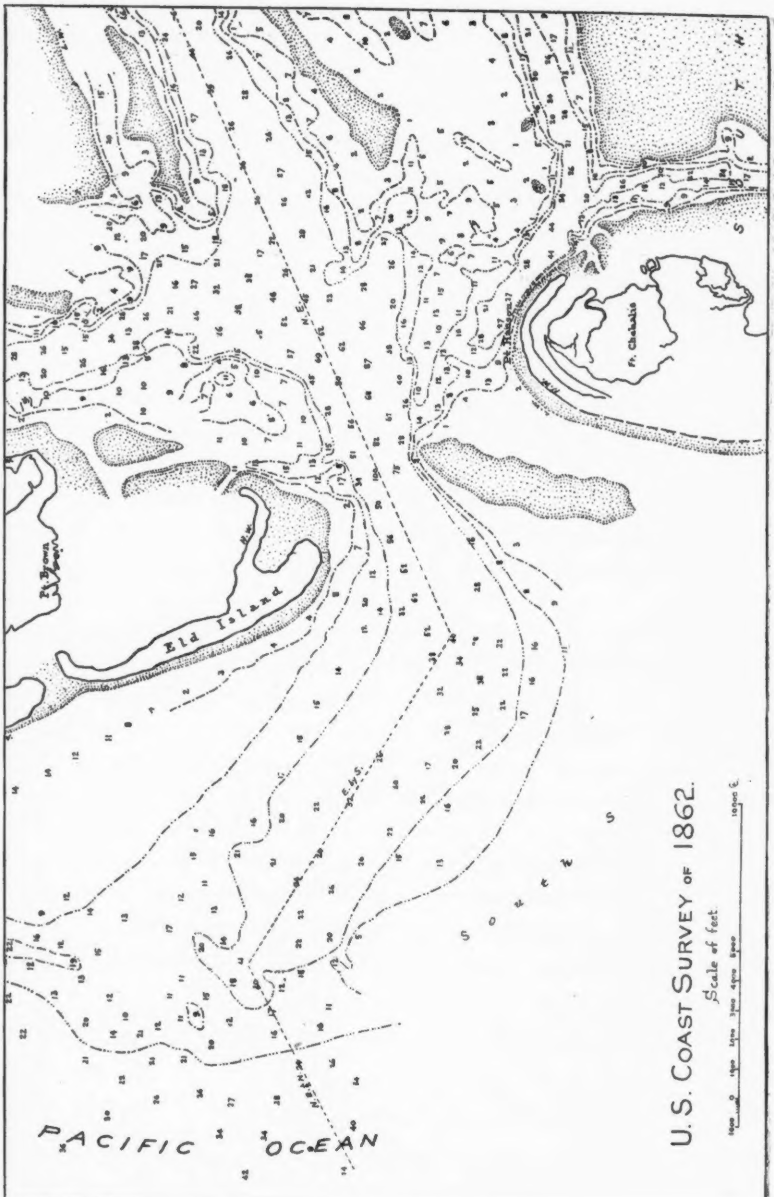

Eld Island
PACIFIC OCEAN
U. S. COAST SURVEY OF 1862.
Scale of feet

FIG. 1.

from it by a tidal lagoon called Johns Bay. The same formation, but less marked, exhibits itself on the south. Maps of the entrance made at different periods show marked changes in the formation about these limiting points.

There seems to be a definite cycle of changes in the end of the north spit abreast of the harbor throat. First, there is an island near the deep water shown on the 1862 map as Eld Island, see Fig. 1. This island gradually works to the north, and finally attaches itself to and encircles Point Brown, as shown on the 1891 map, Fig. 2. This ribbon gradually wears away, as shown on the 1894 map, and, as this proceeds, the island begins to form near the deep channel toward Point Hanson. This island is now in progress of formation, although it was not possible at the time of the recent survey to get any definite soundings on it, to show it in detail. It is, however, indicated in position on the map.

The changes about Point Hanson are less in extent than those about Point Brown. The 1862 map shows an extension of the Point Hanson sands farther to the north than they appear at any subsequent period.

Deep water in the harbor throat lies next to Point Hanson, and occupies about one-third of the width between it and Point Brown. The other two-thirds is occupied by the changeable sandspit above described, which is partly bare at extreme low tide. In the harbor throat the flowing waters have gouged a deep hole. The greatest depth found at the time of the survey was 100 ft., but depths as great as 106 ft. are shown on some of the Coast Survey charts.

A cross-section of the harbor throat is shown in Fig. 3, and upon the same sketch are shown the longitudinal profiles along the entrance channels and the longitudinal profile of the proposed jetty.

The cross-sectional areas of the channel between Points Brown and Hanson are as follows:

	Square feet.
At mean high tide..............................	293 760
At mean tide....................................	245 960
At mean low tide................................	200 560

This would give, in an ordinary tide, an average velocity through the harbor throat of 3.04 ft. per second, or about 2 miles per hour. In a maximum tide this average velocity would be increased to 4.47 ft.

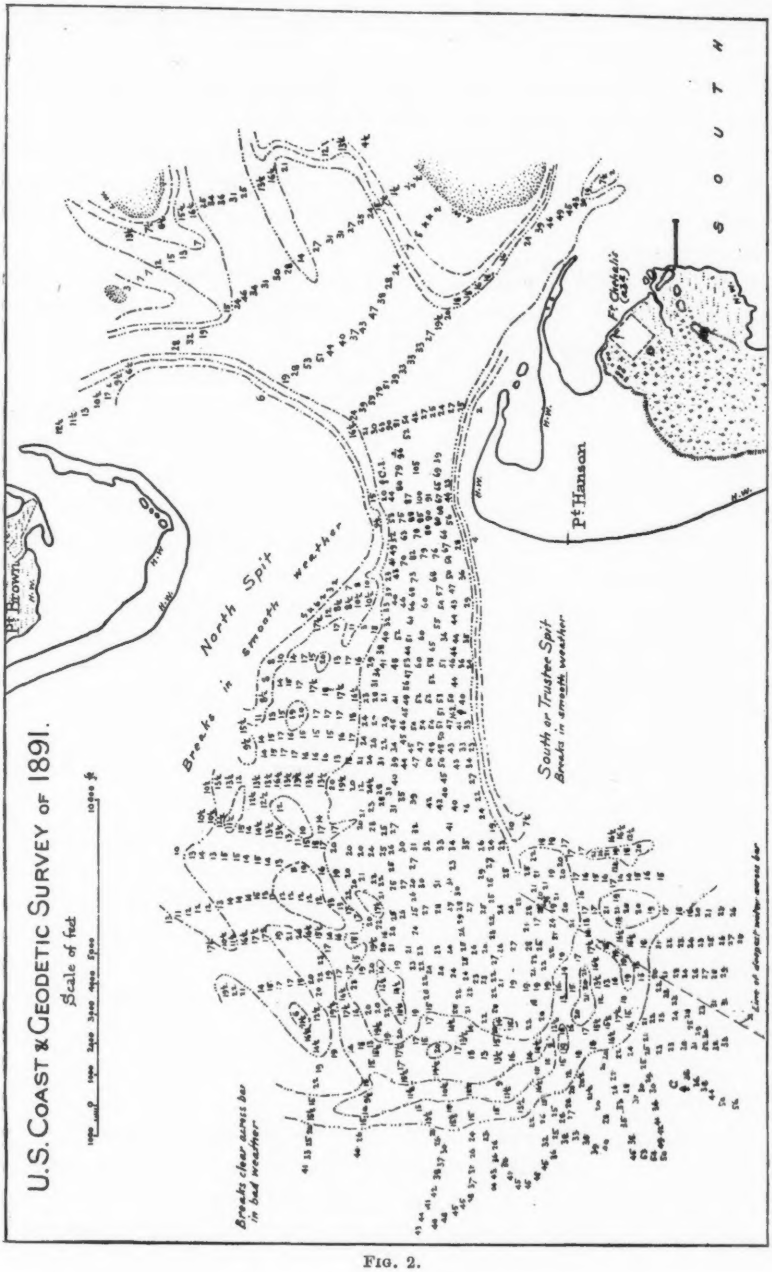

U.S. Coast & Geodetic Survey of 1891.
Scale of feet
North Spit
Breaks in smooth weather
South or Trustee Spit
Breaks in smooth weather
Pt Hanson
Pt Brown
Ft Chehalis
SOUTH
Breaks clear across bar in bad weather
Line of deepest water across bar

FIG. 2.

per second, or about 3 miles per hour, with extreme velocities of 6 to 7 miles per hour.

Points Brown and Hanson are the terminations of low peninsulas which separate Grays Harbor from the ocean. The Point Brown peninsula is about 7 miles long, and the Point Hanson peninsula about 4 miles long. Both average 1 mile in width and both are covered with a dense jungle of timber to within about 1½ miles of their extreme ends.

In front of the entrance to Grays Harbor the 100-fathom curve lies 32½ statute miles from the general shore line. The 10-fathom curve lies 4½ statute miles in front of the general shore line. This gives a general slope to the ocean bed in front of the harbor of 3.2 fathoms or 19.2 ft. per statute mile. The 10-fathom curve lies but about 3 000 ft. in front of the outer 3-fathom curve of the bar. This gives a very steep slope in front of the bar of 1.4 ft. in 100 ft., a slope which is very conducive to the success of the plan of improvement proposed, as the bar will not be readily formed in advance of its present position after a deep channel is scoured across it.

The Grays Harbor bar projects beyond the general coast line in a crescent shape, as is well shown on Coast Survey charts Nos. 6 100 and 6 400. The material of the bar is fine gray sand. Directly opposite the entrance the outer 3-fathom curve is 4 miles beyond the middle of the harbor throat. The general distance between the inner and outer 3-fathom curves varies greatly, but it may be said to be approximately ½ mile in the vicinity of the bar channel.

The best bar channel varies in depth from 12 to 20 ft., and in direction from nearly south to northwest. As nearly as can be ascertained there is a great cyclic change in the principal bar channel, occurring in about 35 to 40 years, and a lesser one occurring at short and irregular intervals. The greater movement seems to follow or be coexistent with the building up and movement of the sand island off the southern end of Point Brown. When the island is well formed, the best entrance channel is to the northwest; and as the island travels north, the channel travels south.

The entrance channel is at its best when leading out to the southwest. From this position it swings gradually around to the south, until it reaches a direction that is nearly due south. As this movement takes place the channel becomes deeper, but narrow and crooked,

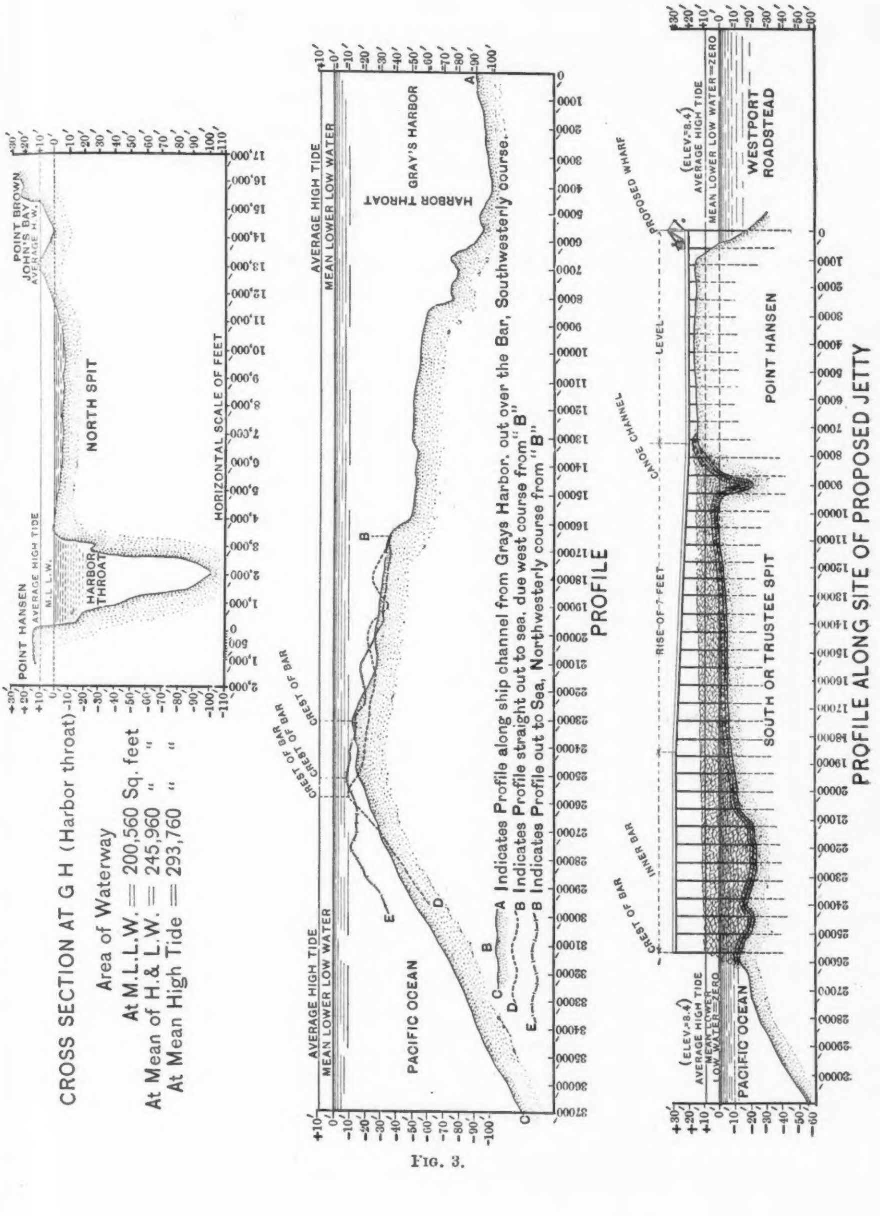

CROSS SECTION AT G H (Harbor throat)
Area of Waterway
At M.L.L.W. = 200,560 Sq. feet
At Mean of H.& L.W. = 245,960 " "
At Mean High Tide = 293,760 " "
POINT HANSEN
AVERAGE HIGH TIDE
M.L.L.W.
HARBOR THROAT
NORTH SPIT
POINT BROWN
JOHN'S BAY
AVERAGE H.W.
HORIZONTAL SCALE OF FEET
AVERAGE HIGH TIDE
MEAN LOWER LOW WATER
GRAY'S HARBOR
HARBOR THROAT
PACIFIC OCEAN
CREST OF BAR
A Indicates Profile along ship channel from Grays Harbor, out over the Bar, Southwesterly course.
B Indicates Profile straight out to sea, due west course from "B"
B Indicates Profile out to Sea, Northwesterly course from "B"
PROFILE
PROPOSED WHARF
(ELEV.=8.4)
AVERAGE HIGH TIDE
MEAN LOWER LOW WATER=ZERO
WESTPORT ROADSTEAD
POINT HANSEN
CANOE CHANNEL
LEVEL
RISE OF 7 FEET
SOUTH OR TRUSTEE SPIT
INNER BAR
CREST OF BAR
PACIFIC OCEAN
PROFILE ALONG SITE OF PROPOSED JETTY

FIG. 3.

and immediately following this it breaks out to the west and commences to swing around to the southward again. The smaller movement, from west around to south, occurs many times more than the greater from northwest around to south. This constant, gradual movement of the channel from north to south has an important bearing upon the plan of improvement recommended. It is this movement or tendency which it is believed will make a single jetty interposed in its way effective in maintaining a permanent deep bar channel.

During the winter, when the southwest storms prevail, the water is deeper in the entrance bar channel than during the summer. This is attributed to the heavy freshets more than counteracting the effects of the storm to close the bar. The bar channel closes to some extent during the summer, when the milder northwest winds prevail, during which time the sands of the higher spits and beaches are dry, and the ebb and flow of the tide is small, and there are no freshets.

Littoral Current.—In the vicinity of Grays Harbor there is a littoral current, the general resultant of which tends to the north. This general current to the northward is ordinarily considered as the eddy caused by the southward flowing Japanese Gulf Stream. It is noticed all along the coast and has received the name of the Davidson Inshore Eddy Current. While the resultant littoral current is to the north, it ordinarily follows the direction of the prevailing winds in the immediate vicinity of the land, moving to the south in summer and to the north during winter. In intensity it is said to reach as high as 2½ miles per hour either way.

Surveys.—There have been five surveys of the Grays Harbor entrance made, covering a period of 32 years. Three were made by the Coast Survey in 1862, 1883 and 1891, and two by the United States Engineer Department, 1881 and 1894.

Charts of the surveys of 1862 and 1891 are given in Figs. 1 and 2. The survey of 1894 is shown on a larger scale in Plate XIII. The bar and bar channel shown on the charts of 1891 and 1894 are similar, and unlike those shown on the 1862 chart.

In 1862 the bar channel was to the northwest of the harbor throat; in all the others it is to the southwest. The complete charts of 1891 and 1894 show the bar to be in a lumpy condition. The survey of 1862 shows but one channel, that leading to the northwest. It is quite pos-

sible, and in the author's opinion very probable, that a good channel existed also to the southwest, although not shown on the chart. The survey was made in a sailing brig, and the soundings were apparently confined almost entirely to the waterway leading out to the northwest, which was probably the best known channel at the time. No soundings are shown to the south and southwest.

There is another condition bearing upon the question of improvement which is not fully shown on the charts. This is the existence of a channel leading to the south around and close in to Point Hanson. This is indicated on the map of 1862, and slightly on the map of 1881, and was observed, but not surveyed, in 1894. It is marked on the map as Canoe Channel from the fact that it is used by fishermen and others going in and out in small boats, in good weather, when the sea is smooth.

Plan of Improvement.—The plan proposed for the improvement of the entrance to Grays Harbor is based upon the theory of controlling the ebbing and flooding waters to a sufficient extent to concentrate and direct upon the bar in a fixed location a much greater portion of these waters than would naturally go there, thereby scouring a channel across the bar of depth ample for all purposes of navigation and permanent in position.

The large tidal volume and discharge from Grays Harbor furnish the means, if properly directed, to secure a bar channel of satisfactory depth. The ordinary mean tidal discharge is estimated at 748 000 cu. ft. per second. Its tremendous scouring effect is shown at the harbor throat, where, as long as the harbor has been known, depths of 100 ft. have been maintained.

It is recognized that in order to produce a satisfactory channel it is necessary to add to a natural channel but a limited proportion of the ebbing and flooding waters now going elsewhere, provided these waters can be kept flowing there permanently. In other words, it is by no means necessary, as it is not desirable, to direct all the ebbing and flooding waters into a single narrow bar channel. It is also recognized that the safety of any controlling works demand that but a small proportion of the flowing waters be fully controlled by artificial means.

Based upon the ordinarily accepted theories of harbor improvement, as shown by the plans adopted for various places in the United

States, the plan for Grays Harbor would be to confine the outflowing and inflowing waters between two jetties more or less parallel and converging upon the bar at a sufficient distance apart to concentrate and direct the waters in a single bar channel. Recent experiences and consideration of the subject convince the author, however, that at Grays Harbor this ordinary plan can be deviated from, and that one jetty, if properly located, will accomplish results fully as good as two, at a vastly less cost, and without any undue or destructive strain upon the structure from the developed currents.

At Coos Bay, Ore., the one jetty that has been built has caused a bar channel to be developed and maintained fully equal to that which it was hoped to accomplish with two jetties. There the jetty has been interposed against the slow, constant movement of the bar channel to the northward. The plan proposed for Grays Harbor is based largely upon the results obtained and studies made at Coos Bay. At the mouth of the Columbia the single jetty has been eminently successful. Here there is a rocky headland on the north, and the situation is apparently quite different. In reality, however, it is much more similar than it appears at first sight, for the limiting of the waters to the north of the bar channel is due, not to the Cape Disappointment headland, but to Peacock Spit and its tailing sands. There are many points of resemblance in the Grays Harbor problem to that at the Columbia River.

The plan proposed for the improvement of Grays Harbor entrance consists of a single high-tide, rubblestone jetty, founded on Point Hanson, and directed out to sea in a direction nearly due west.

The receiving wharf is located on the south channel inside the harbor sufficiently far to enable stone scows, etc., to be unloaded in safety. The jetty tramway approach thence extends nearly due west 7 300 ft. across the head of Point Hanson. The jetty commencing at the high-tide line also extends nearly due west 10 900 ft. along the South or Trustee Spit at a distance of about 1 000 ft. from its outer steep slope, cutting off the inner or Canoe Channel. Leaving Trustee Spit, it curves to the southwest for 7 300 ft., reaching the crest of the bar at about the present location of the mid-channel bar buoy. Here it stops.

With this location, the water flowing to the southward through the inside coast channel over Trustee Spit, and beyond this to the end of

the jetty, would be stopped from flowing in its present direction, and compelled to go in and out to the north of the jetty. It is believed that these deflected waters, added to the natural waters of the desired channel location, will give an improved bar channel, sufficient for all purposes of navigation.

With the jetty in this location, the slow cyclic movement of the bar channel would be stopped when the latter reaches its best and most satisfactory position, and it is believed that the jetty would maintain it in this position. The jetty would prevent the channel from moving toward the south, and there would be no occasion for it to break out to the west or northwest.

It is this interposition against the gradual movement of the channel that has made the Coos Bay and Columbia River jetties so successful. The same conditions which at Coos Bay have rendered the north jetty effective in maintaining a deep and permanent channel over the bar exist at Grays Harbor, but are reversed. At Coos Bay the bar channel habitually broke out to the west and gradually worked around to the north, getting finally into an awkward trough channel nearly parallel with the coast. The jetty as built is interposed in the way of this gradual channel movement to the northward, and it is to this fact that its good results in giving a permanent location to the bar channel are attributed.

At Grays Harbor the bar channel habitually breaks out to the west and gradually works around to the south, getting finally into an awkward trough channel nearly parallel with the coast. The proposed jetty is located to interpose itself in the way of this gradual channel movement to the southward with the hope and belief that the same resultant action which has been found at Coos Bay will be found at Grays Harbor, with the outcome of giving a deep, permanent, well-directed bar channel.

The situation at Grays Harbor in regard to exposure, latitude, bar changes, and volume of tide water is much more analogous to that at the mouth of the Columbia River than it is to that at Coos Bay. It is in fact very similar to the Columbia. At the Columbia a single south jetty has been projected and constructed, and is eminently successful in giving a deep channel in a permanent location, and this notwithstanding the fact that the entrance between the end of the jetty and Cape Disappointment is over 3 miles in width.

The exposed end of the jetty proposed for Grays Harbor would be nearly head on to the worst storms, those from the southwest, an important point in maintaining its stability. The slightly curved direction given to the jetty trace, convex to the channel, will give the channel whatever advantage there is due to the tendency of tidal flows to follow a convex curve. The channel will also have the direction and location most convenient and desirable for the commerce centering in the harbor.

It was suggested by one in authority that the system of double jetties should be adhered to, the jetties being built about 6 000 ft. apart, protected by groins 500 ft. or more in length, leaving a clear waterway about 4 500 ft. wide. This suggestion was carefully considered, but for the reasons here given was not adopted.

Nowhere on the Pacific Coast, nor on the Atlantic Coast, nor, so far as the author is aware, in the world, has the attempt been made to control between parallel jetties a tidal flow of anywhere near the magnitude of that at Grays Harbor, and the author would view with great apprehension the attempt to build the jetties to so control the tidal flow. With an average tidal flow and the rivers tributary to the bay in their ordinary condition there would be, in a channel 4 500 ft. wide and an average of 30 ft. deep at low tide, a mean tidal velocity of 4.9 ft. per second, or 3.3 miles per hour. In this case the maximum velocity would be about 6 miles per hour. With a maximum tidal run-out in such a channel there would be a mean tidal velocity of 7.2 ft. per second, or 4.9 miles per hour, and a maximum velocity of about 9 miles per hour. This is without taking into consideration the rivers tributary to the bay, which would add considerably to the volume and velocity of the current if they were in a freshet stage.

Such velocities as these are, in the author's opinion, incompatible with safety when they result from the artificial contraction of a waterway by comparatively frail structures built upon shifting sands and exposed to the wave action on a very stormy coast. It must be admitted that such a great volume of water as that of Grays Harbor, moving with the stated velocities and aided by wind and waves, is a tremendous power and liable to play havoc with any works exposed to its full force. This is to be avoided, if possible, and it is with this end in view that it is proposed to control as small a portion of the flowing waters as possible consistent with attaining the desired end.

At the harbor throat or gorge the cross-sectional area of the waterway at mid-tide is 245 960 ft., and here depths of 100 ft. are regularly maintained. With a width of 4 500 ft., this same cross-sectional area could only be obtained by an average depth throughout of 54 ft. It could, therefore, naturally be expected that between the jetties spaced as indicated, there would be depths exceeding 60 ft., which depth confined in the immediate vicinity of a rubble stone jetty founded on sand would be very threatening, even though the jetty were guarded by long and expensive groins.

At only two points on the Pacific Coast have systems of parallel jetties controlling the tidal expense in one concentrated stream been practically completed—at Wilmington and at Yaquina. At Wilmington the tidal flow is only one-one hundred and twentieth of that at Grays Harbor, and at Yaquina only one-twentieth of that at Grays Harbor.

The author's experience is such as to convince him that it would probably be found impossible to build a second jetty at Grays Harbor within 6 000 ft. of a first one by the ordinary method which has been and is being used on this coast. As this second jetty would be built out, the currents would scour a channel in front of it until the depths would become too great for the construction of a pile and timber tramway. As the seas in the locality are too rough to permit of the construction of the jetty from floating plant, there would be the necessity of devising new methods of construction, which would surely be far more expensive than those ordinarily used.

As indicative of the unusual magnitude of the work of improving Grays Harbor by a system of parallel jetties in the manner suggested, a table is given on page 350 showing the mean range of the tide, the tidal area, the mean tidal discharge, and distance apart of the proposed jetties for Grays Harbor and other harbors of the United States, where jetties have been or are being constructed, concerning which the author has been able to get information.

On the direct line from Point Brown to Point Hanson, the line upon which the greatest depth is found, the midtide section has an area of 246 000 sq. ft. The maximum depth on this line is about 100 ft., a depth entirely inadmissible in the vicinity of jetties unless the jetties be protected by very long and costly groins.

If a system of double jetties were adopted it would be necessary to provide a minimum waterway between them fully equal to 246 000

sq. ft. Assuming an average midtide depth of 20 ft., this would require that the jetties should be spaced fully 2 miles apart, if built to high tide.

If this width were narrowed there would be a tendency to dangerous undermining of the jetties, which would increase as the width diminished. Within this necessary width of 2 miles there would undoubtedly develop one or more channels of much greater depth than 20 ft. at midtide. Such a channel might occupy any position between the jetties, and, on leaving their concentrating influence, would have

Locality.	Mean range of tide.	Tidal area.	Mean tidal discharge per second.	Distance between jetties at sea ends.	Remarks.
	Feet.	Square miles	Cubic feet.	Feet.	
PACIFIC:					
Columbia River......	6.2	*140	1 000 000	18 900	High tide single jetty. Width between end of jetty and Cape Disappointment.
Grays Harbor.........	8.4	96.8	748 000	6 000	Reduced to about 4 500 ft. by groins Suggested width.
San Diego............	3.7	25.5	97 000	4 000	High tide single jetty. Approximate width between end of jetty and Point Loma.
Humboldt Bay........	5.5	24	100 000	2 100	High-tide jetties.
Coos Bay.............	5.5	24	100 000	1 500	" "
Yaquina Bay.........	7.0	5	38 000	900	" "
Siuslaw River	5.2	5.4	30 000	600	" "
Coquille River........	4.1	3 6	15 000	600	" "
Wilmington Harbor..	4.0	2.25	6 000	700	" "
ATLANTIC:					
Galveston Harbor.....	1.1	450	250 000	7 000	High tide jetties.
Charleston Harbor...	5.1	15	170 000	2 900	Low-tide jetties.
Cumberland Sound...	6.0	27	202 000	3 900	" "
Winyaw Bay..........	3.5	12	120 000	4 000	High-tide jetties.
St John's River......	4.3	(?)	76 500	1 600	
Sabine Pass	1.4	120	50 000	1 700	High-tide jetties.
Newburyport.........	7.5	(?)	(?)	1 000	" "

* To Cathalmet.

almost as great latitude in choosing its direction as would be the case of a channel with but a single jetty as directrix. It is therefore believed that it is unnecessary to provide a north jetty or make provision or estimate for any other construction than the south jetty.

It is proposed that the jetty shall extend to the ordinary crest of the bar in its present location. This would give a total length for the structure of 25 500 ft. from the receiving wharf to the end. The jetty proposed is a rubble mound founded on a brush mattress, the

whole built from a pile and timber tramway extending from the shore, the enrockment to be brought well above high tide.

The estimated cost of the work is as follows :

Plant including wharf, engines, derrick, locomotives, cars, machine shop tools, building, stone barges, lumber and brush barges, etc.	$153 955
Tramway, 25 500 ft. long	102 590
Mattress foundation, made of small spruce trees laid diagonally	61 900
Enrockment. Rock brought from the Columbia River, 441 100 tons at $1.07	471 977
Groins. Five, each 200 ft. long	40 940
Shore protection	15 000
Engineering, superintendence, office expenses, etc., 5 per cent	42 318
	$888 680
Contingencies, accidents, delays, repairs, care of property, etc., about $12\frac{1}{2}$ per cent	111 320
	$1 000 000

The cost of the double jetty system applied to Grays Harbor, as suggested, would be about $2 500 000. Owing to difficulties that might be encountered in building the second jetty, and the possible necessity of greatly strengthening both jetties, it might be even more than this.

It is not to be denied or contended that when the single jetty is completed it may be found essential to its success to put in some shore protection or other minor works, to develop and render stable the best condition of the North Spit, but the expense of such works would be slight.

Vol. XXII. AUGUST, 1896. No. 6.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publication.

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SOCIETY AFFAIRS.

PAPERS.

ILLUSTRATIONS.

American Society of Civil Engineers.

OFFICERS FOR 1896.

President, THOMAS C. CLARKE.

Vice-Presidents.

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BENJAMIN M. HARROD,

Term expires January, 1898:
WILLIAM R. HUTTON.
P. ALEXANDER PETERSON.

Secretary, CHARLES WARREN HUNT.

Treasurer, JOHN THOMSON.

Directors.

Term expires January, 1897:
WILLIAM H. BURR,
JOSEPH M. KNAP,
BERNARD R. GREEN,
T. GUILFORD SMITH,
ROBERT B. STANTON,
HENRY D. WHITCOMB.

Term expires January, 1898:
AUGUSTUS MORDECAI,
CHARLES SOOYSMITH,
GEORGE H. BENZENBERG,
GEORGE H. BROWNE,
ROBERT CARTWRIGHT,
FAYETTE S. CURTIS.

Term expires January, 1899:
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THOMAS W. SYMONS.

Assistant Secretary, JOHN M. GOODELL.

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DANIEL BONTECOU,
CHARLES WARREN HUNT.

Special Committees.

ON UNIFORM STANDARD TIME:—Sandford Fleming, Charles Paine, Theodore N. Ely, J. M. Toucey, T. Egleston.

ON ANALYSIS OF IRON AND STEEL:—Sub-Committee of the American Society of Civil Engineers (of the International Committee on Standards for the Analysis of Iron and Steel, of which Prof. J. W. Langley is Chairman)—Charles B. Dudley, William Metcalf, Thomas Rodd, A. E. Hunt.

ON UNITS OF MEASUREMENT:—George M. Bond, William M. Black, R. E. McMath, Charles B. Dudley, Alexander C. Humphreys.

The rooms of the Society are open from 9 to 17 o'clock each business day, except Saturday (when they are closed at 15 o'clock), and at other times on application to the Janitor.

HOUSE OF THE SOCIETY—127 EAST TWENTY-THIRD STREET, NEW YORK.

Vol. XXII. AUGUST, 1896. No. 6.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS.

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MINUTES OF MEETINGS.

OF THE SOCIETY.

June 3d, 1896.—The meeting was called to order at 20.15 o'clock. Vice-President William R. Hutton in the chair; Charles Warren Hunt, Secretary, and present, also, 105 members and 23 visitors.

The minutes of the meetings of May 6th and 20th, 1896, were adopted as printed in *Proceedings* for May, 1896.

William H. Burr, M. Am. Soc. C. E., described some experimental pile-driving through new stone-filled cribwork, and the subject was discussed by Messrs. George S. Greene, Jr., William R. Hutton, L. L. Buck, Rudolph Hering, George H. Thomson and William H. Burr.

Charles O. Brown, M. Am. Soc. C. E., described the engineering features of the proposed building law for New York City, and the subject was discussed by Messrs. William E. Worthen, C. T. Purdy, George A. Just and George H. Thomson.

Ballots were canvassed, and the following candidates declared elected:

As Members.

Nathaniel Henry Hutton, Baltimore, Md.
Herbert Waldo York, New York City.

As Associate Members.

Philip Aylett, Algiers, La.
John Albert Cosmus, Elizabeth, N. J.
George Samuel Hayes, New York City.
Allen Hazen, Boston, Mass.
William Faitoute Keene, Central Falls, R. I.
Arthur Marquis Scripture, New Hartford, N. Y.

The Secretary announced the election by the Board of Direction on June 2d, 1896, of the following candidates:

As Juniors.

Gustave Maurice Braune, Athens, Pa.
Adolph George Wulff, Cincinnati, Ohio.

The Secretary announced the death of James Hugh Stanwood, elected Associate Member October 3d, 1894; died May 24th, 1896.

Adjourned.

TWENTY-EIGHTH ANNUAL CONVENTION OF THE SOCIETY HELD AT SAN FRANCISCO, CAL., JUNE 29th TO JULY 3d, 1896.

First Session, Monday, June 29th, 1896.—The Society met at 11 o'clock, George E. Gray, Hon. M. Am. Soc. C. E., in the chair; Chas. Warren Hunt, Secretary.

Col. Gray, in calling the Convention to order, spoke as follows:

Gentlemen, Members of the American Society of Civil Engineers:

"On behalf of the Members of this Society, resident on the Pacific coast, we are pleased to extend to visiting Members and guests of the Society from the East, gathered here to hold the Annual Convention, a hearty and sincere welcome. It is our desire that you shall enjoy the opportunity to inspect, so far as your limited time will permit, some of the works executed under the direction of civil engineers, many of whom are Members of this Society. In the route to this coast, over the Rocky Mountains and the Sierra Nevadas, the eastern Members have observed, have judged somewhat, the energy put forth to make the iron and steel highway practicable. While there are no displays of monumental show, at the same time every effort has been put forth to make the road of so stable a character as to fully meet the wants and comfort of the people, furnishing a great national highway from ocean to ocean. On your arrival, you could not but observe the ferry system

connecting the great railways of the country with this city. We claim that it provides the best and most complete service for the smallest fare in any country. Your attention will be called to the cable system of street railroads, in the home of the first cable railroad inaugurated. We shall also call your attention to the great capabilities and field for active work around the bay of San Francisco. There is also the Golden Gate Park, redeemed from the drifting sands of the ocean; the Seal Rocks, adjacent thereto; the Sutro Baths and Heights, from which an unsurpassed view of the Pacific Ocean may be had.

"After a brief glance over this city, you will be asked to contemplate some of the achievements of the Spring Valley Water Company whose works supply this city. The great concrete dam near San Mateo is worthy of your attention, and had you time, it would be of interest to examine this system fully; to observe the water-shed, and the supply and quality of the water, it being among the purest furnished to any city in the Union, or the world. In the language of one of our worthy Past-Presidents, who examined this very fully in his capacity as an engineer, 'there is no supply that could be better; the water-shed is owned principally by the company, the whole nearly in a state of nature, and the supply the condensation from the broad Pacific from which source no contamination can come.'

"From the Spring Valley dam it is intended to give you a glimpse of Palo Alto, the city of the Leland Sanford Junior University, an institution founded by Leland Stanford and Jane Lathrop Stanford, as a memorial to their beloved son Leland Stanford, Jr. They have endowed this university munificently to aid the youths of both sexes to acquire the knowledge and character to make them useful and good citizens of the Republic. From Palo Alto you will have a bird's-eye view of the Santa Clara Valley and its riches, then by rail to the Hotel Del Monte at Monterey, then to the Santa Cruz big trees, etc.

"It had been hoped by the Resident Members of the Pacific Slope, that, had time permitted, you would visit the southern part of the State, including a trip over the Tehachapi Mountains, viewing the loop which was considered a wonder at first, but has been copied so often since that it has lost much of its novelty; to take a look over the City of Angels and the surrounding country, the beautiful orange, lemon and walnut groves, the vineyards and orchards, the palatial residences and beautiful homes, nearly all on lands that were quite recently destitute of grass and water, but now made fertile by judicious irrigation through canals, ditches, etc., illustrating the skill, experience and judgment of the civil engineer. Could you continue a little further southward to the great Colorado River, before reaching it the route would carry you (to the surprise of many) over the great Colorado Desert, where the line of the railroad for over 60 miles is laid below the level of the ocean, and in the deepest place 267½ ft. below tide.

"On the return from Monterey and Santa Cruz the route contemplated leads to Oregon and thence homeward. Our hope is that the tour will add to the pleasure and knowledge of the visiting Members, and, while the visit will have been all too brief, that it will tend to bind more fully all the Members in a better acquaintance with each other. We trust all may return in safety to their homes with only pleasant memories of the visit to San Francisco. Again we say, a sincere welcome.

"It is my pleasure to introduce as Chairman of this Convention our distinguished member and friend, a resident of this city, Col. George H. Mendell."

Thereupon Colonel Mendell assumed the chair.

The Chair announced that it was necessary at this Convention to elect a nominating committee.

The Secretary then made the following statement:

"At the Annual Convention of 1895 the Nominating Committee was elected in the following manner: The President appointed a Member of the Society resident in each of the seven geographical districts as temporary chairman of that district, who called the Members of his district together, and presented to the Business Meeting of the Convention two nominees, and the Society then elected a member of the Nominating Committee from that district.

"Under Art. VII, Sec. 2, of the Constitution, there were elected as members of the Nominating Committee, June 18th, 1895, to serve two years, the following Members: District No. 1, Edward P. North; District No. 2, W. A. Brackenridge; District No. 3, L. Frederick Rice; District No. 4, Percival Roberts, Jr.; District No. 5, J. D. Hawks; District No. 6, L. W. Rundlett; District No. 7, G. A. Quinlan.

"The Geographical Districts from each of which a representative is to be elected to serve on the Nominating Committee for the next two years were arranged by the Board March 3d, 1896, and published in *Proceedings* for March, 1896. The divisions are identical with those of last year and are as follows:

District No. 1.—The territory within 50 miles of the Post Office of the City of New York.

District No. 2.—The remainder of the States of New York and New Jersey and Canada.

District No. 3.—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island and Connecticut, and all foreign countries.

District No. 4.—Pennsylvania, Delaware, Maryland and District of Columbia.

District No. 5.—Michigan, Ohio, Indiana, Illinois and Wisconsin.

District No. 6.—Minnesota, Iowa, Missouri, Kansas, Nebraska, North Dakota, South Dakota, Washington, Montana, Wyoming, Idaho, Colorado, Utah, Oregon and Nevada.

District No. 7.—Virginia, West Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Louisiana, Florida, Texas, Tennessee, Kentucky, Indian Territory, Oklahoma, New Mexico, Arizona, Arkansas and California."

The Chair requested the Members from each of the districts to assemble and to present one or two nominees to the Business Meeting, to be held later in the day.

The Secretary presented in abstract a paper entitled the "Flow of Water in Wrought and Cast-Iron Pipes from 28 to 42 Ins. in Diameter," by Isaac W. Smith, M. Am. Soc. C. E.

A paper entitled "Improving the Entrance to a Bar Harbor by a Single Jetty," by Thos. W. Symons, M. Am. Soc. C. E., was then presented in abstract by the Secretary, who also read a written discussion by Lewis M. Haupt, M. Am. Soc. C. E., and the subject was discussed orally by Messrs. George F. Allardt, Geo. H. Mendell, James D. Schuyler, Jos. M. Knap and Geo. T. Prince.

The Secretary then presented in abstract a paper on "The Construction of a Light Mountain Railroad in the Republic of Colombia," by E. J. Chibas, Assoc. M. Am. Soc. C. E., and also written discussions by Messrs. E. Sherman Gould and José R. Villalon.

A communication from W. H. Kennedy, M. Am. Soc. C. E., Chief Engineer Oregon Railway and Navigation Co., offering the use of a special train for an excursion to the Cascade Locks on the arrival of the party at Portland, Ore., was read by the Secretary for the information of Members.

Adjourned to 15 o'clock.

Second Session, Monday, June 29th, 1896, 15 o'clock.—Col. Geo. H. Mendell in the chair; Chas. Warren Hunt, Secretary.

The Secretary presented an abstract of a paper by A. C. Cunningham, M. Am. Soc. C. E., entitled, "The Condition of Steel in Bridge Pins," and also read written discussions by Geo. T. De Forest, Assoc. M. Am. Soc. C. E., and George S. Morison, Past-President Am. Soc. C. E. The subject was discussed orally by William Metcalf, Past-President Am. Soc. C. E., and the author.

A paper entitled "A Water Power and Compressed Air Transmission Plant for the North Star Mining Company, Grass Valley, Cal.," by A. D. Foote, M. Am. Soc. C. E., was presented in abstract by the Secretary, and was discussed orally by S. S. Wheeler, M. Am. Soc. C. E.; John N. Chester, Assoc. M. Am. Soc. C. E.; William Doble, Esq., and the author.

Adjourned.

BUSINESS MEETING.*

First Session, Monday, June 29th, 1896, 16 o'clock.—Director Jos. M. Knap in the chair; Chas. Warren Hunt, Secretary.

Nominations were received for members of the Nominating Committee from each of the seven geographical districts, and the following were elected for two years, as provided in Art. VII, Sec. 2, of the Constitution:

District No. 1, John G. Van Horne; District No. 2, Palmer C. Ricketts; District No. 3, A B. Hill; District No. 4, John E. Greiner; District No. 5, Geo. S. Pierson; District No. 6, Wm. H. Kennedy; District No. 7, Wm. G. Curtis.

The Secretary reported that no formal reports from Special Committees had been received, but that from correspondence with the chairmen of the committees "On Analysis of Iron and Steel" and "On Units of Measurement" he had learned that it was probable that a report would be received from each of these committees in time for publication and presentation to the Society at the next Annual Meeting.

* For full report see page 115.

The Secretary read the report of the Committee on the Award of the Collingwood Prize for Juniors.*

The Secretary presented a letter signed A. Hortense Swift, executrix, enclosing an extract from the codicil to the will of McRee Swift, F. Am. Soc. C. E., and a check for $1 000, the amount of the bequest to the Society.†

On motion duly seconded it was unanimously resolved that the appreciation of the Society for the bequest be expressed to Mrs. Swift.

The Secretary read a letter from J. F. Wallace, M. Am. Soc. C. E., President of the Western Society of Engineers, inviting, on behalf of that Society, the Members of the Society to participate in an excursion over the Chicago Drainage Canal on their return to the East."‡

Adjourned.

Second Session, Monday, June 29th, 1896, 20 o'clock.—Director Jos. M. Knap in the chair; Chas. Warren Hunt, Secretary.

The Secretary, in the absence of President Thomas Curtis Clarke, read his address entitled "Science and Engineering." §

A letter signed by the President and Secretary of the Merchants' Association of San Francisco‖ was read by the Secretary.

William Metcalf, Past-President of the Society, then made an address to the meeting.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

June 2d, 1896.—Seven Members present.

H. G. Prout, M. Am. Soc. C. E., and Ira A. Shaler, M. Am. Soc C. E., were appointed to serve with the Secretary as a committee to award the Collingwood Prize for Juniors.

The resignation of Charles R. Boyd, M. Am. Soc. C. E., was presented and accepted.

Matters in relation to the architecture and construction of the New Society House were considered.

Applications were considered and other routine business transacted.

One candidate was elected as an Associate and two as Juniors.

Adjourned.

Note.—No meeting of the Board of Direction was held during the Annual Convention, as provided in the Constitution, there being no quorum present.

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* See page 118.

† See page 119.

‡ See page 120.

§ See *Transactions* Am. Soc. C. E., Vol. xxxv, page 508.

‖ See page 122.

REPORT IN FULL OF THE BUSINESS MEETING HELD DURING THE ANNUAL CONVENTION OF THE SOCIETY AT SAN FRANCISCO, CAL., JUNE 29th-JULY 3d, 1896.

First Session, Monday, June 29th, 1896.—Director Joseph M. Knap in the chair; Chas. Warren Hunt, Secretary. Meeting called to order.

The Chair.—Gentlemen of the Society, we will now open the Business Meeting. Our Constitution requires that we hold a Business Meeting at the Annual Convention of the Society. We have the minutes here of the last Business Meeting of the Society in New York, which can be read if you wish it. If not called for, they will be dispensed with. As there seems to be no call, we will dispense with them.

One object of this Business Meeting is to allow Members to bring up anything they wish. There is one thing, however, that must be brought up, and that is the nomination and election of a nominating committee selected from the seven districts into which this country is divided. It has been the custom heretofore to adjourn for a few minutes to allow the Members to get together. The Secretary will read the districts.

The Secretary then read a list of the districts.*

The Chair.—There has been no regular rule as to how many nominations are made, although it has been customary in some cases to nominate two. The first man nominated has generally been elected. I would make this suggestion, that it might be well to simply agree on the man you want to nominate, and nominate one.

The Secretary.—It is not necessary for the Society to elect any man whom the district proposes.

The Chair.—If anyone is nominated who does not suit the Convention it can elect anyone else, but as a rule a man selected by the district is elected. I will now declare an adjournment for five minutes,

(During the recess the Members from the different districts met and selected candidates for the Nominating Committee.) Recess.

The Chair.—The Convention will come to order. I will ask Mr. Wagoner, the President of the California Association, to make an announcement.

Mr. Luther Wagoner.—The California Association is co-operating with the local committee and trying to entertain our guests, and the Chief Engineer of the Harbor Commission, Mr. Howard Holmes, has asked me to say that he will be pleased to receive all, or as many as wish, to examine the Harbor Works at 8.45 in the morning. That will give 45 minutes before the excursion at 9.30, and it is necessary to do that on account of the tide. It will be impossible to do it on the return of the boat in the afternoon. Announcement of Excursion.

While I have the floor I wish to say that we have also carefully

* See page 112.

considered the matter of Wednesday, and have thought best to plan the excursion something like this. Assemble at the "Presidio" at 9 o'clock, and there transportation will be provided to visit the fortifications, returning about 12 o'clock to visit the Gas Works, where luncheon will be provided at Harbor View, and arriving at the ferry at three o'clock for a trip to the State University at Berkeley,

Mr. Wm. G. Curtis.—I would like to suggest that the final determination of that programme be left until to-morrow, to be determined upon the steamer. Parties can be formed to make those or other excursions better on that occasion.

Election of Nominating Committee.

The Chair.—I will now ask for the Chairman of District No. 1 to make a nomination.

The Chairman of District No. 1 nominated for a member of the Nominating Committee John G. Van Horne, of New York City.

The Chair.—Mr. John G. Van Horne is nominated by District No. 1. Are there any other nominations?

No other nominations were made, and nominations were closed.

It was moved and seconded that the Secretary be empowered to cast the vote. Motion carried, and the Secretary cast the vote for John G. Van Horne.

The Chairman of District No. 2 nominated Palmer Chamberlaine Ricketts, of Troy, New York.

No other nomination was made, and nominations were closed. It was moved and seconded that the Secretary be empowered to cast the vote for the Society. Motion carried, and the Secretary cast the vote for Palmer Chamberlaine Ricketts.

No member being present from District No. 3, nominations were called for, and Albert Banks Hill, of New Haven, Conn., was placed in nomination. No other nomination was made, and nominations were closed. It was moved and seconded that the Secretary be empowered to cast the vote for the Society. Motion carried, and the Secretary cast the vote for Albert Banks Hill.

The Chairman of District No. 4 nominated John Edwin Greiner, of Baltimore, Md. No other nomination was made, and nominations were closed. It was moved and seconded that the Secretary be empowered to cast the vote for the Society. Motion carried, and the Secretary cast the vote for John Edwin Greiner.

The Chairman of District No. 5 announced that that district nominated two candidates, namely, George Spencer Pierson, of Kalamazoo, Mich., and John Findley Wallace, Chicago, Ill.

A rising vote was taken resulting in twenty votes being cast for Mr. Pierson, and fourteen for Mr. Wallace. The Chair thereupon declared George S. Pierson elected for District No. 5.

The Chairman of District No. 6 announced that that district nominated two candidates, George Herndon Pegram, of Omaha, Neb., and William Harlin Kennedy, of Portland, Ore.

A rising vote was taken resulting in a tie vote, each candidate having received eighteen votes. Thereupon one of the members who had voted for Mr. Pegram changed his vote to Mr. Kennedy. The Secretary then announced the vote as nineteen for Mr. Kennedy and seventeen for Mr. Pegram. The Chair thereupon declared William Harlin Kennedy elected for District No. 6.

Election of Nominating Committee (continued).

The Chairman of District No. 7 nominated William Giddings Curtis, of San Francisco, Cal. No other nomination was made, and nominations were closed. It was moved and seconded that the Secretary be empowered to cast the vote for the Society. Motion carried and the Secretary cast the vote for William Giddings Curtis.

Nominating Committee Announced.

The CHAIR.—I will state that the Nominating Committee consists of fourteen; seven were elected last year, for two years, so there will be seven hold over and seven have been elected now. They meet some time this fall and make their nominations accordingly. I will now announce the appointments as made this afternoon. District No. 1, John G. Van Horne; District No. 2, Palmer Chamberlaine Ricketts; District No. 3, Albert Banks Hill; District No. 4, John Edwin Greiner; District No. 5, George Spencer Pierson; District No. 6, William Harlin Kennedy; District No. 7, William Giddings Curtis. We are ready now for any business that any Member wishes to bring up.

The SECRETARY.—The Special Committees appointed by the Society are supposed to report at one of the two general meetings each year. No formal report has been received from any of the three special committees for presentation to this Convention, but it is perhaps proper that a statement should be made of the status of the work of the Committees on Units of Measurement and on Analysis of Iron and Steel.

Statement in regard to Committee on Units of Measurement.

At the Annual Meeting, January 16th, 1896, an informal report of the Committee on Units of Measurement was accepted as a progress report, and the Committee was continued and requested to submit a final report at the next Annual Convention, that is, this Convention. Since that date the resignation of the then Chairman of the Committee, Prof. E. A. Fuertes, and of Prof. George F. Swain, a member of the Committee, have been tendered and accepted, and appointments have been made by the Board of Direction as follows:

As Chairman of the Committee, George M. Bond, M. Am. Soc. C. E. Mr. Bond has been for some time a member of the Committee; and as members of the Committee, Chas. B. Dudley, M. Am. Soc. C. E., and Alexander C. Humphreys, M. Am. Soc. C. E.

Under a resolution of the Board of Direction, approved at the Annual Meeting of the Society in January, 1895, all reports of committees must be placed in the hands of the Secretary thirty days prior to one of the general meetings, and issued to all Members in printed form before the date of the meeting at which they are to be pre-

sented. The Secretary has been in correspondence with the Chairman of the Committee on Units of Measurement, hoping to secure the report which the last Annual Meeting instructed the Committee to make, but owing to the delay which has resulted from the reorganization of the Committee a general report of progress is all that can be expected. Mr. Bond has informed the Secretary that he feels confident the Committee can arrange for a meeting in the fall, and that a report will be forthcoming at the next Annual Meeting.

Statement in regard to Committee on Analysis of Iron and Steel.

The Committee on Analysis of Iron and Steel, which is a Sub-Committee of this Society of the International Committee on Standards for the Analysis of Iron and Steel, of which Prof. J. W. Langley is Chairman, has not been able to prepare a report. Dr. Charles B. Dudley, the Chairman, has stated to the Secretary that the Sub-Committee has been working very hard with the hope of being able to get its report ready for presentation at this Convention, but that the amount of work necessary is simply appalling. He writes as follows:

"Each member of the Committee has to be consulted, and each man has to do chemical work. Moreover, at the last meeting of the Sub-Committee, at which a method was practically agreed upon by the five chemists, it was decided that before having this method made public it should be submitted to a few chemists in this country for trial. This trial takes some time, and it has not been possible for each of the chosen chemists to drop everything instantly and take hold of this trial work. The Committee is therefore not able to get a report ready to put in print and submit it to each member of the Committee of the Society in time for the June meeting."

Dr. Dudley states further that the Committee is very loath to have the report go over to the next semi-annual meeting, and as there is a great demand among the chemists of the country for this report, is very anxious to get it into shape and have it published at the earliest possible moment.

The Secretary has stated to the Chairman of the Committee that as soon as the report is received it will be published in *Proceedings*, and will, under the rules, be brought before the Society at the next Annual Meeting in January. The Committee now consists of Dr. Charles B. Dudley, William Metcalf, Thomas Rodd and A. E. Hunt.

I have also to present the following report:

Report on Collingwood Prize for Juniors.

The Committee appointed by the Board of Direction to award the Collingwood Prize for Juniors has decided unanimously, under Clause VI of the Code of Rules for its award, that the interest of this fund for 1895 shall be expended by the Board of Direction for the purchase of books or instruments to be offered as a premium for the second best paper of the next year in which more than one paper of sufficient value is published.

(Signed) H. G. Prout,
Ira A. Shaler,
Chas. Warren Hunt.

Dated N. Y., June 17th, 1896.

Bequest of McRee Swift.

I also have to report to the Society the receipt of the following communication:

NEW BRUNSWICK, N. J.,
June 12th, 1896.

The American Society of Civil Engineers.

GENTLEMEN,—The enclosed extract from the will of Mr. McRee Swift contains his instructions concerning a bequest of $1 000 to the American Society of Civil Engineers.

A check for $1 000 from Mr. Swift's estate is also enclosed.

Assuring you that it gives me much pleasure to comply with these instructions, testifying to Mr. Swift's great interest in the Society, of which he was one of the original members,

I remain,
Yours very sincerely,
(Signed) A. HORTENSE SWIFT,
Executrix.

The extract from the will, or rather from the codicil, is as follows:

"I give and bequeath to 'The American Society of Civil Engineers,' incorporated under the laws of the State of New York, and having its present house at No. 127 East Twenty-third Street in the City of New York, the sum of one thousand ($1 000) dollars, to be invested by said Society, and the income thereof devoted by it to the purchase of rare books and maps for the library of said Society and models for its museum.

"This gift is made in memory of my father, General Joseph G. Swift. born in 1783, died in 1865, the first graduate of the Military Academy at West Point, afterwards Chief of the Corps of Engineers of U. S. Army, and, subsequently to his resignation from the army, Chief Engineer of many undertakings, among them the New Orleans and Ponchartrain Railroad in 1829, and the Harlem Railroad in 1832."

I might say, sir, that the Secretary has acknowledged the receipt of the letter and of the enclosure.

It was moved and seconded that the appreciation of the Society for the bequest be expressed to Mrs. Swift. The motion was unanimously carried.

The CHAIR.—Before adjourning I wish to make a remark in regard to the present attendance at this convention. It has been a matter of regret in the Eastern delegation that our number is not larger. We fear that our friends of the Pacific Slope will think that their time and thoughtful arrangements for our entertainment have not been appreciated, but I can assure them that is not the case. There have been, perhaps, two causes for the small attendance; one, the want of time on the part of the members, and the other the want of money. The replies to our last circular indicated that many members had not the time to come; others had plenty of time and not the money; and I was somewhat astonished and wondered why they did not convert a portion of that spare time into money, and it brought into question in my mind the truth of the saying that time is money.

There is, perhaps, another thing that is a reason for this. There has been a law in regard to the attendance at our conventions—it seems to have been an established rule—that the number of members in attendance is inversely as the square of the distance of the geographical center of membership from the place of the convention. Last year when we held our convention in Boston, that distance was about 800 miles. This year it is about 3 000 miles. You take the proportion 900 to 64, or 450 to 32. Last year in Boston there were 450, and therefore this year 32 would be the right number here, and as we have about three times that number, I think we can congratulate ourselves.

Invitation from Western Society of Engineers.

The SECRETARY.—I will read a letter which has just been handed to me from Mr. J. F. Wallace, President of the Western Society of Engineers.

WESTERN SOCIETY OF ENGINEERS,

CHICAGO, June 24th, 1896.

THOS. C. CLARKE, Esq.,
President American Society of Civil Engineers,
in Convention, San Francisco, Cal.:

DEAR SIR,—On behalf of the Western Society of Engineers, I extend an invitation to as many Members of the American Society of Civil Engineers, their ladies and friends, as may find it convenient to return to the East by way of Chicago, to participate in an excursion of inspection over the Chicago Drainage Canal as guests of the Western Society of Engineers; and would ask that I be informed as to the probable number who will avail themselves of this invitation, also the most convenient date, in order that the Entertainment Committee of the Western Society may make necessary arrangements for the excursion.

Yours truly,
(Signed) JOHN F. WALLACE,
President.

The CHAIR.—What will be your action upon that matter? Shall a committee be appointed to look into it or not? My view of it is that there will be comparatively few returning that way, a very few returning together.

No action was taken.

Announcement in regard to Oakland Reservoirs.

Mr. JAMES D. SCHUYLER.—I want to say that since I came to San Francisco this time I have learned of an interesting piece of work, which is especially interesting to me, because I have taken a good deal of interest in the asphaltum lining of reservoirs. In Oakland there is now in progress a piece of work in that direction, and a reservoir has already been lined without the use of any other material whatever, and another reservoir is in process of construction. It is a trip of about three or four hours to visit these reservoirs and see the work in progress, and those who are interested in that particular line of work might care to go over and see it on Wednesday. The asphalt company of which I made the inquiry in regard to this work kindly presented to

the Society a series of photographs of the work which the Members might care to inspect. In a general way the photographs contain this information on the back. The depth of excavation is 21½ ft.; side slope, $\frac{2}{3}$ to 1; lining, 4 ins. thick, covered with asphaltum; on top of the slope proper there is a wall 7 ft. in height, 2 ft. thick at the base, 12 ins. at the top, one-half underneath the surface of the ground; capacity about 3 500 000 galls. It was constructed this year and completed about the 15th of June. I ask the indulgence of the Members of the Society for calling their attention to this, for it is a little specialty of mine which I have been interested in, and I prepared a paper for the Society some two years ago describing the reservoirs in Denver of the same material.

Adjourned until June 30th, 1896, 20 o'clock. **Adjournment First Session.**

Second Session, Tuesday, June 30th, 1896, 20 o'clock.—Director Joseph M. Knap in the chair; Chas. Warren Hunt, Secretary. **Meeting called to order.**

The Chair.—The Constitution provides that the President shall deliver an address at the Annual Convention. The President, Mr. Clarke, being unavoidably absent, has designated the Secretary to read his annual address. After this address is delivered by Mr. Hunt, we may call upon one of our eastern Members for a few remarks. Mr. Hunt, will you kindly commence the address?

The Secretary.—Before reading the address I will read a letter from the President. **Letter from T. C. Clarke, President.**

New York, June 18th, 1896.

To the Members of the American Society of Civil Engineers, in Convention assembled in San Francisco.

Gentlemen,—I have delayed writing this letter until now, hoping that it would not be necessary.

It is now, with feelings of deep regret, that I am obliged to ask your kind forbearance for my absence from this important Convention. Engagements entered into before the place or time was fixed make it impossible for me to be with you.

I will not take up time in telling you what a disappointment this is to me.

I send you my address, which will be read to you by the Secretary, and if you are influenced in any degree by the advice which I have given, I shall feel that my term of office has not been a failure.

With great respect, I am

Your obedient servant,

(Signed) Thomas Curtis Clarke,

President Am. Soc. C. E., 1896.

The Secretary then read the address of the President, entitled, "Science and Engineering." * **President's Address read.**

* See *Transactions*, Vol. xxxv, page 508.

Letter from Merchants' Association.

The Secretary then presented the following letter:

MERCHANTS' ASSOCIATION,
SAN FRANCISCO, June 29th, 1896.

W. G. CURTIS, Esq., C. E.,
Secretary Committee of Arrangements,
American Society of Civil Engineers, City.

DEAR SIR,—On behalf of the Board of Directors and members of the Merchants' Association, we hereby extend cordial greetings to the Members of the American Society of Civil Engineers who are now honoring our city by their presence in convention.

The Merchants' Association has always held to the principle of having fit men in charge of public works, and has endeavored to call attention to the advisability of placing our public works in the charge of educated and trained engineers.

We hope that the visit of the American Society of Civil Engineers will tend to advance this principle, and that our people will learn more of the standing and dignity of the profession so well represented by your Society.

It will afford us pleasure to have any of the delegates interested in municipal work to call at the offices of the Association, and no doubt, through your extensive knowledge and experience, we will receive much valuable information and advice.

Sincerely yours,
MERCHANTS' ASSOCIATION.
(Signed) F. W. DOHRMANN,
President.
J. RICHD. FREUD,
Secretary.

The CHAIR.—Although the main matter for which this meeting has been called has been attended to, viz., the hearing of the President's address, I am sure you will not regret having the opportunity to listen to one of our Past-Presidents, Mr. William Metcalf, of Pittsburgh, who has consented to address us to-night.

Address by Past President Wm. Metcalf.

Mr. METCALF.—Mr. President, Ladies and Gentlemen. After traveling through about 3 000 miles of all sorts of dust, and through three days of the most wonderful and energetic hospitality of this town, I was informed last evening, after a hearty dinner, that I had been picked upon by the Board of the Society, consisting of the Chairman and Secretary, to make a little address to-night, and to express the feelings and sentiments of the visiting engineers toward the engineers of the Pacific Slope and the people who have treated us so kindly. Immediately afterward I was called in to a reception and kept until after midnight, and after a small amount of sleep I was called out on the Bay and kept there all day. I therefore beg to be excused, if instead of trying to make a speech I have to confine myself very closely to a few notes and my spectacles, and I shall confine myself almost entirely to making a speech to those people who put such an imposition on this meeting and not to our good friends here who have been so kind.

Address by Mr. Metcalf (continued).

I propose to say a few words in regard to the Pacific Slope, what there is here and what it needs, for the benefit of those who are now making their first visit here. I think it is conceded that all history shows that civilization has always advanced from the East to the West. It has finally reached the last barrier in the circumnavigation of the globe, the Pacific Slope—in fact, the new civilization and enlightenment has already flashed across the great ocean and is enlivening the people on the other side from where civilization started, who have been sleeping for untold centuries. But civilization, the movement from the East to the West, cannot stop here, although it appears to be lagging, and there are one or two reasons why, and I propose to try to show them to our visiting Members.

This State of California, if you look at a properly designed map such as I found to-day in San Francisco, and which therefore must be right, is larger than New York, New Jersey, Maine, Massachusetts, New Hampshire, Connecticut, Ohio, Delaware and Rhode Island combined. In fact the map shows these States put into California in white, and while the rest of California was left black, I don't know but the black is pretty nearly as big as the white. The population of that great area is probably less than that of New York City—certainly less than that of Chicago.

Oregon, I believe, if I remember the map rightly, is twice the size of Pennsylvania, or more, with a population less than that of Allegheny County in the latter State. Washington is one and one-half times as large as Pennsylvania, with a smaller population than one of the large counties of Pennsylvania. The area is large, and the population is small in numbers—that is about all that there is small on this Pacific coast. In fact, when you come out here you will learn if you stay a little while that it is necessary, in order to know anything or to realize anything about this coast, to multiply everything by three. The trees grow to be 129 ft. in circumference and 365 ft. high. The ordinary pines, you will find thousands of them standing in the hills here, are 6 to 8 ft. in diameter and 150 to 200 ft. high, or at least three times as large as the average tree of the East. The common elderberry bush of the East, of which we are all so fond, grows here to a tree 12 ins. through the trunk and 30 ft. high and so on.

But there are some things wanting on the coast, and I propose to show what they are, first showing some things that are not wanted. It is perfectly clear to anybody who came over with us that there are no engineers wanted here, that is, that there is no want of engineers. We are very proud of our monuments in the East and our little horseshoe curves, and all that, but surely anyone who has seen the monuments of this coast, who has gone over the curves and grades we came over and the loops we came around, and those who are to go North

Address by Mr. Metcalf (continued). will not only go around horse-shoes and loops, but actually through a kind of cork-screw, turning themselves around backwards, will certainly conclude that there is no need of railroad engineers. The hydraulic work that we know of throughout the mines in this State shows that that kind of engineering is quite up to the requirements of the age. We were shown to-day that mechanical engineering is not at all behind any of our Eastern States. We know from your beautifully lighted buildings and streets that there is no need of electrical engineers. Clearly there is no want of engineers. Nor is there any want of architects, as the beautiful buildings in this city show. Certainly there is no want of artists, as we all know who looked at the papers this morning. There is no want of harbors; there might be more, but looking on the map from Cape Horn to Alaska there are but three great harbors on the coast, San Diego, San Francisco, and Puget Sound, and they all belong to these three States; so that there is room here for commerce to come and provision made to receive it when it does come.

The climate is all that could be asked for, as we have evidenced daily. The products of the soil are so great, so abundant, so luscious, certainly there is no lack there; and beauty everywhere; and clearly there is no lack of brains, as anybody can see who looks on the faces of the friends who have treated us so nobly while we have been here, and therefore it would seem that there is hardly anything lacking in this country.

If you take a look at our old countries on the Gulf, and consider the Atlantic coast as a great, powerful, highly developed and skilful right arm of industry, producing everything that can be required, and consider the Mississippi Valley containing the great vital organs of production and sustenance and the great mountain ranges and the little ranges running out from them as the great back-bone, breast-bone and frame-work of this great continent, we have left the Pacific coast as the left arm, powerful, ready, potential, but undeveloped, and it is to that development that attention should be turned.

The things wanted are, then, a canal across the Isthmus so that it shall be impossible for any trusts or combinations to corner or hamper the free commerce of the nation from one side to the other. You cannot corner the Atlantic and you want a canal—I don't say whether it is Panama or Nicaragua or Tehuantepec. I see some of my New York friends say, "Oh, no you don't; it is nonsense;" but I know New York is a little bit afraid of her supremacy because the world is moving westward.

The other great want is clearly shown from statistics that I gave in the beginning of this little speech, and that is, farmers. You want from the granite hills of New England and the beautiful valleys and hills of New York and Pennsylvania the hardy farmers to come out

here, the man who can come with his family, and not only support it, but prosper and thrive and save on 40 or 50 acres in your beautiful country, on your wonderfully fertile soil; and when you get that, the great left arm of this nation will soon develop all the power that is potential in it, and this nation will become one, all-powerful, ambidextrous and unconquered. Those are the two things that you need here. I was informed that, after having told my friends from the East what this part of the world needs, I was to present a series of resolutions of thanks. In doing this at this time I feel a little in the position of the good deacon who was called upon to ask a blessing over a meal, but the host, while the deacon was getting ready, pitched into the viands, and the deacon looked on for awhile and said: "For all we are about to receive, and for all we have received, may we be devoutly thankful." **Address by Mr Metcalf (continued).**

I offer the following resolution:

"*Resolved*, That California is great, and the whole Pacific slope is greater.

"*Resolved*, That the products of her soil are great and her people are much greater.

"*Resolved*, That her flowers and fruits are luscious and beautiful, and her women excel them all so greatly that we must say they are most beautiful and lovely beyond compare.

"*Resolved*, That we find ourselves unable to express ourselves, and therefore we give it up and consign ourselves without further thought to the inexpressible delight of our visit."

All in favor of those resolutions please say aye. If there are any contraries they had better retire.

The CHAIR.—There being no further business, the meeting will be declared adjourned.

Thereupon the Convention adjourned *sine die*. **Final Adjournment.**

EXCURSIONS, ETC., DURING THE TWENTY-EIGHTH ANNUAL CONVENTION OF THE SOCIETY.

The arrangements for the convenience of Members and their families attending the Convention comprised the following itinerary: Leaving New York City *via* the New York Central and Hudson River Railroad June 22d, 1896, at 18 o'clock, to Buffalo; thence *via* Lake Shore and Michigan Southern Railway to Chicago; thence *via* Chicago, Rock Island and Pacific Railway to Manitou, Colo., arriving there June 25th at 8.45 o'clock. Remaining at Manitou for twenty-four hours, a special train was provided *via* the Denver and Rio Grande Railway, through the Royal Gorge, the Grand Cañon of the Arkansas, etc., to Glenwood

Springs, where a stop of four hours was made; thence *via* the Rio Grande Western, through the Wahsach Mountains and Jordan Valley *via* Salt Lake City to Ogden, Utah. From Ogden *via* the Southern Pacific Company through Nevada and California to San Francisco, arriving on the evening of June 28th.

Return trips over all the transcontinental lines were arranged for in order to suit individual taste or convenience.

The local Committee of Arrangements consisting of Geo. E. Gray, Chairman; Col. Geo. H. Mendell, Wm. G. Curtis, James D. Schuyler and Wm. B. Storey, Jr., arranged a programme which was carried out as follows:

Monday, June 29th.—A reception tendered to the Visiting Members and their ladies was held at the Palace Hotel in the evening.

Tuesday, June 30th.—Excursion by steamer around San Francisco Bay, including a visit to the Union Iron and Shipbuilding Works. Luncheon was served on board the steamer.

Wednesday, July 1st.—The day was spent in an excursion by carriage through the Government fortifications, etc., to the Cliff House, where the entire party were entertained at lunch by Mayor Sutro. After visiting the Sutro Baths all were driven through the Mayor's private grounds, and the beautiful Golden Gate Park.

Thursday, July 2d.—Through the courtesy of the Southern Pacific Company a special train conveyed a large party to San Mateo where they were met by special conveyances and driven to and across the dam of the Spring Valley Water Company. The entire party was entertained by the Water Company at lunch under the trees. The return was by another road to San Mateo where the special train was again boarded. A stop was made at Palo Alto, allowing an inspection of the buildings of Leland Stanford, Jr., University; thence to Monterey. The night was spent at the Hotel del Monte.

Friday, July 3d.—In the morning a beautiful 17-mile drive was tendered to the party by the Southern Pacific Company, and after lunch at the hotel the special train conveyed the party to San Francisco *via* Santa Cruz and over the Santa Cruz Mountains, stopping at one of the "Big Tree" groves.

Saturday, July 4th.—Leaving San Francisco at 9 o'clock by special train the day was spent in an inspection of the Electric Power Plant at Folsom, with an interesting visit to the State Prison at that place, and the shops of the Railroad Company at Sacramento. In the evening the homeward journey was begun *via* the Southern Pacific Company's Northern Line to Portland, arriving early on the morning of the 6th.

Monday, July 6th.—Special cars were furnished by the courtesy of the Portland Traction Company, and under the guidance of F. I. Fuller, M. Am. Soc. C. E., General Manager, the party had a delight-

ful trolley ride to Portland Heights. At 10 o'clock, by invitation of the Oregon Railway and Navigation Company, William H. Kennedy, M. Am. Soc. C. E., Chief Engineer, the visitors, accompanied by many residents of Portland, left by special train for a trip up the Columbia River to the Cascade Locks. Stops at many interesting points were made. At the locks lunch was served, and, returning to Portland, the northward journey was resumed. Tacoma was reached in the evening.

Tuesday, July 7th, 1896.—Local Members of the Society at Tacoma entertained the party during the day. There was an excursion by trolley to the park and thence by steamer on Puget Sound. An enjoyable reception was held at the Tacoma Hotel in the evening.

At Tacoma the Convention party from the East disintegrated, returning either by the Northern Pacific or Canadian Pacific Railroad.

THE ATTENDANCE AT THE TWENTY-EIGHTH ANNUAL CONVENTION.

The following 62 Members were in attendance at the Convention:

A. L. Adams.....San Francisco, Cal.
W. C. Ambrose.....Bakersfield, Cal.

C. C. Babb........Washington, D. C.
C. K. Bannister........Ogden, Utah.
A. J. Bowie......San Francisco, Cal.

J. N. Chester......Indianapolis, Ind.
L. V. Clarke, Jr....Philadelphia, Pa.
A. C. Cunningham......Albany, N. Y.
Wm. G. Curtis....San Francisco, Cal.
E. B. Cushing ......Houston, Texas.

G. L. Dillman.........Alameda, Cal.
J. J. Donovan......Fairhaven, Wash.

Fred. Eaton.......Los Angeles, Cal.

J. C. L. Fish, Stanford University, Cal.
A. De W. Foote....Grass Valley, Cal.
J. L. Frazier.....San Francisco, Cal.

W. D. Gelette....San Francisco, Cal.
C. E. Goad........ Toronto, Can.
Geo. E. Gray.....San Francisco, Cal.
G. S. Greene, Jr...... New York City.

E. F. Haas...........Stockton, Cal.
W. H. Hall.......San Francisco, Cal.
A. McL. Hawks .....Tacoma, Wash.
D. C. Henny.....San Francisco, Cal.
Theo. Hoech......Washington, D. C.
M. G. Howe........Houston, Texas.
Chas. Warren Hunt..New York City.
Randell Hunt....San Francisco, Cal.

J. D. Isaacs......San Francisco, Cal.

Washington Jones..Philadelphia, Pa.

J. M. Knap..........New York City.

W. S. Lincoln........St. Louis, Mo.
Thos. D. Lovett.......Cincinnati, O.

J. C. McClure......Los Angeles, Cal.
Louis R. McLain....Fitzgerald, Fla.
D. E. Melliss......San Francisco, Cal.
G. H. Mendell....San Francisco, Cal.
M. Merriman..South Bethlehem, Pa.
Wm. Metcalf..........Pittsburg, Pa.
J. E. Mills..............Quincy, Cal.
C. E. Moore........Santa Clara, Cal.
T. W. Morgan.........Oakland, Cal.

F. S. Odell. ......Mt. Vernon, N. Y.

Geo. S. Pierson....Kalamazoo, Mich.
O. R. Pihl..............Portland, Ore.
G. T. Prince............Omaha, Neb.

G. A. Quinlan.......Houston, Texas.

J. Ramsey, Jr... ....St. Louis, Mo.
Benj. Reece............Chicago, Ill.
A. S. Riffle...........Portland, Ore.
F. Riffle.........San Francisco, Cal.

J. D. Schuyler.....Los Angeles, Cal.
E. G. Spilsbury.......Trenton, N. J.
Wm. B. Storey, Jr. San Francisco, Cal.
C. R. Suter......San Francisco, Cal.

F. E. Trask ....Ontario, Cal.

Otto von Geldern. San Francisco, Cal.

J. H. Wallace....San Francisco, Cal.
D. W. Wellman......Los Gatos, Cal.
S. S. Wheeler........New York City.
Jos. M. Wilson.....Philadelphia, Pa.
E. T. Wright.......Los Angeles, Cal.

The total attendance at the Convention was as follows:

Members of the Society (in all grades)	62
Guests, members of the Technical Society of the Pacific Coast and of the California Association of Civil Engineers and other engineers who attended the meetings	37
Ladies and guests accompanying the eastern party	30
Total	129

The above comprises those who registered. There were besides many who attended the sessions of the Convention who failed to register, as well as many ladies and other guests who took part in the receptions, excursions, etc.

ANNOUNCEMENTS.

MEETINGS.

Wednesday, September 2d, 1896, at 20 o'clock, the first regular meeting of the season of 1896–97 will be held at the Society House, 127 East Twenty-third street, New York. The paper for the evening is by Elon Huntington Hooker, Ph.D., entitled "The Suspension of Solids in Flowing Water."

Wednesday, September 16th, 1896, a paper by E. Sherman Gould, M. Am. Soc. C. E., on "The New Water-Works of Havana, Cuba," will be presented.

Wednesday, October 7th, 1896, at 20 o'clock, a paper on "The Reconstruction of the Grand River Bridge," by W. A. Rogers, Jun. Am. Soc. C. E., will be presented.

These papers are all printed in this (August) number of *Proceedings*, and correspondence upon them is invited and may be sent to the Secretary by mail. If received in time such correspondence will be presented to the Society at the meeting at which the paper is read.

NEW SOCIETY HOUSE.

Work at the site of the New Society House has been started. At the present writing the lots have been excavated.

Since the last publication the following additional subscriptions have been received:

Edward D. Adams	$100
Julius W. Adams	200
M. de Teive e Argollo	100
James E. Boatrite	20
Chas. B. Brush	100
William Carter	10
G. L. Christian	5
F. S. Curtis (additional)	200
Frederic Danforth	20
J. J. Donovan	15
Charles Francis	50
W. H. Gahagan	50
Edward A. Greene	25
J. C. Irwin (additional)	10
W. H. Jaques (additional)	15
J. M. Knap (additional)	$100
C. H. Lindenberger	5
Wisner B. Martin	25
A Member (additional)	25
Dickinson McAllister	10
Thomas C. Meyer	35
O. F. Nichols	50
Samuel Rea	100
Addison M. Scott	50
H. R. Stanford	20
W. G. Triest	50
J. W. Walker	100
E. Wegmann	25
W. J. Wilgus	15

Total subscription to date	$19 010
Total subscription paid to date	15 580

MEMOIRS OF DECEASED MEMBERS.

FREDERICK ELLSWORTH SICKELS, M. Am. Soc. C. E.*

Died March 9th, 1895.

Frederick Ellsworth Sickels, famous as the inventor of the Sickels cut-off, a device by means of which the plans of James Watt for utilizing the economic advantages of expanding steam became for the first time thoroughly and practically applicable, and of many other no less ingenious if not equally important inventions, died of heart failure at Kansas City, Mo., at the age of 76 years, on March 9th, 1895. The modern factory, stationary, steam engine is substantially the work, in its evolution from the old Newcomen engine of 190 years ago, of three men: James Watt, who converted the machine of which Newcomen was the real inventor, from its primitive and enormously wasteful form into a comparatively efficient apparatus by securing reduction of internal wastes from about 95% to perhaps 30 or 40% by the adoption of a condenser separate from the working cylinder and by the use of a steam jacket, while improving at the same time its thermodynamic action, to such extent as the devices available at the time permitted, by the employment of a cut-off arrangement acting on a crude system of valve gearing; Frederick Sickels, who produced the first practicable drop cut-off gearing for the rotatory engine; and George Corliss, who devised a refined and specially contrived type of engine peculiarly adapted to the successful utilization of the ideas of Watt and of Sickels, and the highest refinement of steam engine construction of the time. Watt was unable to avail himself fully of the advantages of his own plan of expansion of steam by closure of the induction valve at an early point in the stroke of the piston, in consequence of two facts. Steam-pressure was always too low in his engines to permit any considerable expansion, and even were the pressures higher, the rudeness of his devices and the ineffectiveness of his provisions for insuring steady rotation of the engine shaft precluded the employment of now familiar methods of expanding steam behind the piston. Sickels provided a system of construction and operation which permitted the detachment of the valve from its moving mechanism, and allowed it to drop back into its seat, thus almost instantly effecting closure at any desired point; while the use of a dash-pot containing water, oil, or air checked its fall as it approached its seat closely, and thus evaded the danger and annoyance consequent upon unrestricted impact. Corliss perfected the engine later by adopting reduced clearances, partially balanced sliding valves moving with accelerated or retarded velocities close to the

* Memoir prepared by Robert H. Thurston, M. Am. Soc. C. E.

cylinder; a steam and an exhaust valve at each end, opening quickly and widely, detached automatically, as previously practiced by Sickels, dropping quickly, closing instantly, and moving comparatively little while closed. The invention of Sickels was an essential element of success in the steam-engine of the nineteenth century and the name of Frederick Ellsworth Sickels rightfully stands beside that of James Watt, both as an inventor and as a builder, for he built numerous engines, stationary and marine, and gave a half-century of busy life to the work.

Sickels was a mechanic and an inventor by nature and inspiration. He was born in 1819 at or near Camden, N. J., received a common school education, and was then employed as rodman, at the age of 17, on the Harlem Railway, but promptly accepted the opportunity then offered him of an apprenticeship under the famous mechanic and engine-builder, James P. Allaire of New York. His father, John Sickels, who was an alumnus of Columbia College, later a physician and at one time Health Officer of New York, is said to have disapproved of his choice of a vocation, but the genius of the youth determined his future, and he completed his apprenticeship at the Allaire Works, and his became, as has been said by one of his biographers, "the only one of all the great names since James Watt to add a radically new and important elemental idea to the theory of steam-valve action, and to couple his new thought with mechanical details of such apt suitability as to bring it easily into the range of common practice,"* and this was before he had attained his majority. The prime necessity for successfully putting into operation the idea of Watt and of producing a good expansion gear was ability to open wide the steam port, and to close it at the right moment in such manner as to cut off the steam supply instantly, giving a square corner on the indicator diagram and converting energy thermodynamically by as nearly adiabatic expansion as possible throughout the remainder of the piston stroke. This the Sickels drop cut-off accomplished actually and satisfactorily.

The invention of Sickels, for the first time in the history of the steam engine and in actual every-day practice, produced a distribution of steam approximating and closely coinciding with the ideal described by Watt in his patent of 1782, giving an indicator diagram with a sharp cut-off corner. This is one of the essential factors of maximum economy of operation of the engine. Its introduction immediately effected great improvement in current practice, and designing and constructing engineers have never ceased from that time to adhere to the principles and methods then first illustrated fully in application. Watt had proposed the expansion of steam by early cut-off, but he found, on attempting its introduction, what were insuperable difficulties in his time, in the irregular action of the engine, the impossibility of effecting prompt cut-off with his mechanisms, and the

* C. T. Porter.

ignorance and obstinacy of the enginemen of the day, and practically gave up the task. He had adopted a ratio of expansion of two as being practicable, and advised four as the probably desirable figure. All his plans came to naught, however, in this field. Sickels overcame every difficulty by his ingenuity, enthusiasm and persistence, and led the way to the standard current practice of our time. His first patents were issued in 1841.

Immediately upon the public announcement of the new device, its introduction began. The firm of Thurston, Green & Company, then already well established and well known for its success in the construction of both stationary and marine engines of the then largest class, purchased the land rights, and Sickels himself, reserving the marine rights, went energetically about the introduction of the invention into the steam merchant and naval fleets. Thurston, Green & Company made the Sickels valve motion their exclusive form of steam valve gearing for mill engines, at once put the new engine on the market, and built many machines of all sizes and classes. Sickels was less prompt in securing a place for his invention on board ship, but he built it into the engine of the *Champion*, one of Vanderbilt's steamboats on Long Island Sound, and later applied it to many steamers on that Sound and on the Hudson River, commencing with the *North America*. The United States Navy, under the supervision of Engineer-in-Chief Haswell, adopted the cut-off and it was employed on the *Waterwitch* in 1847, on the *Powhatan* in 1848, and subsequently on other vessels. It proved perfectly satisfactory on the side-wheel ships of that time, as on all slowly moving engines. On shore the invention found immediate and extensive application and was only driven out, about 1860, by the Corliss engine, patented in 1849, by George H. Corliss, in which the same result was accomplished by devices differing in form from those of Sickels, but always claimed by the latter and by many other engineers to be infringements upon his patents. This claim was passed upon by the Supreme Court of the United States after prolonged litigation, and the decision was rendered in favor of the defendant. No one questions, nevertheless, the claim of Sickels to the distinction of having originally and successfully led the way in the construction of a practicable and successful form of detachable valve gear, a drop cut-off.

Sickels made many other inventions, less well known simply because the greater light of the more important invention obscured that of the lesser ones. He never received full, or even moderate, compensation for the cut-off, or for any other of his characteristically ingenious and valuable devices. Perhaps the most remarkable of these minor devices, both in the eye of the inventor and in the estimation of others, was his steam-steering gear, an arrangement of small steam engines coupled to an ordinary steering gear by means of

which a touch of the finger could be made to control the most powerful and speediest ship when in full career. This invention was first recognized publicly when exhibited at the London International Exhibition of 1862. Very powerful steamships were by that time afloat, and often required several men, sometimes eight or ten, at the helm, to steer the vessel readily and safely. The Sickels steam steering gear enabled one man to direct the course of the largest and fastest ship with as little difficulty as the smallest rowboat. A child might, with this device, put the helm of the *Campania* hard over when at full speed at sea. The arrangement consisted of a pair of small engines the barrel of the ordinary steering apparatus, as ordinarily attached to the steering wheel, and so placed that a small steering wheel attached in such manner as to move the reversing mechanism of the engine, should make the same movements, in so doing, as would the large hand steering wheel. The helmsman operated this little wheel precisely as he was accustomed to handle the wheel of the old gear, and it required no greater effort than was needed to move the steam valve. All large vessels are now thus steered. By an ingenious device, the engines were made to move the helm over to the position desired by the wheelman, and to stop there automatically, following the hand of the steersman with absolutely perfect docility and precision.

Sickels patented altogether about thirty devices, many being improvements in detail upon his principal inventions. He lived and died, however, a "poor inventor," spending the comparatively small returns from his invaluable work, as fast as received, in the prosecution of experiments and in bringing out new devices. He deserved honors second only to those accorded James Watt and he met the fate of the prophet of the proverb who had honor except in his own country; but Sickels was little honored, even abroad. He lived and died almost unknown outside his profession, and so modest, retiring, and disinclined to urge his claims, that he was not extensively acquainted in his own guild. He spent his life mainly in the development and introduction of his inventions, assisted in legal matters by one of the ablest patent lawyers of the time, Mr. Edwin N. Dickinson, and in designing by a brother, Theophilus Sickels, M. Am. Soc. C. E., a well-known member of the engineering profession. After the expiration of the more important Sickels' patents, the brothers worked together in the construction of the Omaha Bridge across the Missouri River, and, later, the great inventor became the Chief Engineer of the Kansas City Water Works, which position he held at the time of his death.

Mr. Sickels' struggles to maintain his rights against infringers of his patents were among the most interesting events of the history of inventions. The suits against Corliss, particularly, brought into court the most famous legal and engineering talent of the time, and Curtis,

Seward, Keller and Dickinson, as counsel, the Renwick brothers, Copeland, Hill, Greene, as experts, and the Thurstons, Benjamin F., famous later as the leading patent attorney and pleader of his generation, and Robert L., the founder of the first Providence Steam-Engine Company of 1837 and of the engine-building firms of Thurston, Gardner & Company and Thurston, Green & Company, gave the controversy added interest by their presence on either side, by their able arguments and their learning, and by their knowledge of contemporary and earlier inventions. These cases were carried up to the Supreme Court, where, after a series of victories in the Circuit Courts, Sickels was finally defeated. Corliss had, as adjudged by the court of last resort, for the first time combined the use of an expansion gear, original in idea with Watt, with a trip cut-off, original in principle with either Watt or some other inventor prior to Sickels, and with the attachment of the governor to determine the point of cut-off, original with Corliss himself in form, but in principle of earlier date, patented by Zachariah Allen, of Providence, as early as 1837, and used abroad in the form of the French cam before Corliss. Sickels was adjudged entitled to an exclusive right to his own particular form of trip and of dash-pot, and Corliss to his own peculiar group of details and method of governing; and the latter was declared not to infringe on the former. Many professionals were led to criticise this decision strongly, but it was subject to no appeal and ended the litigation.

Personally, Mr. Sickels was one of the most attractive and lovable of men. The writer came to know him in the early days of his patent litigations and retained an acquaintance with him throughout the remaining forty years of his life, and was always impressed by his kindliness, his patience, his good temper and his perfect integrity. He was careless in dress and in his habits of business, and curiously absent-minded; but he always adhered steadily to his plans, in spite of all discouragements, and found the way to his end with invariable certainty. He was a man of broad interests and extensive general information, and heartily loyal to his friends, absent or present. He was honest and true from first to last. He was never discouraged, and to the very end held fast to his faith in the ultimate success of his inventions; though without either credit or financial reward adequate to his work. And even when the award of the International Jury of the Centennial Exhibition, at Philadelphia, in 1876, made and signed by a jury composed of a group of the greatest men ever brought together on such an occasion, failed to see the light, he went about his work as placidly and cheerfully and determinedly as ever. The man was the equal of the inventor, the inventor had few equals in history, and few men have done more for the promotion of the development of civilization than did Frederick Ellsworth Sickels.

Mr. Sickels was elected a Member of the American Society of Civil Engineers on January 7th, 1891.

HENRY ISAAC BLISS, M. Am. Soc. C. E.

Died July 10th, 1896.

Henry Isaac Bliss was born at Hartford, Conn., January 8th, 1830. He entered Yale College in 1848, but previous to that time had studied engineering, and had some practically experience. After graduating from the college in 1853, he went at once to Wisconsin and became connected with the construction of the Milwaukee and Fond du Lac Railroad, afterward the La Crosse and Milwaukee Railroad, and now part of the Chicago, Milwaukee and St. Paul system. In the fall of 1854 he returned to Connecticut, and was engaged near Middletown on the construction of the Boston and New York Air Line Railroad until work was suspended in 1855. Then he returned to Wisconsin and made a survey of the La Crosse and Milwaukee Railroad from La Crosse to the Wisconsin River.

In the spring of 1856 he settled in La Crosse, which remained his home up to the time of his death. He at once became engaged in engineering and the real estate business, and made a number of railway surveys. From 1860 to 1884 he was City Engineer of La Crosse, and during this time laid out much of the city as it now stands, and built the municipal water-works plant. He was elected a Member of the American Society of Civil Engineers on September 5th, 1883. Mr. Bliss was in feeble health for some time previous to his death on July 10th, 1896. He leaves a widow and married daughter.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

			Date of Membership.
BROWNLEE, JAMES LEAMAN	349 Corondelet St., New Orleans, La.		May 6, 1896
GARDNER, MARTIN LUTHER	58 Elizabeth Ave., New-ark, N. J.	Assoc. M.	Sept. 2, 1891
		M.	Mar. 4, 1896
HARDEE, WILLIAM JOSEPH	4503 Prytania St., New Orleans, La.		May 6, 1896
MILLER, HIRAM ALLEN	Clinton, Mass.		May 6, 1896
PLIMPTON, ARTHUR LESLIE	439 Albany St., Boston, Mass.		May 6, 1896
STITES, ARCHER COCHRAN	931 The Rookery, Chicago, Ill.	Jun.	Dec. 3, 1890
		Assoc. M.	Nov. 4, 1891
		M.	May 6, 1896
SUTER, CHARLES RUSSELL	533 Kearney St., San Francisco, Cal.		April 1, 1896
YORK, HERBERT WALDO	108 Fulton St., New York City.	Jun.	May 2, 1888
		M.	June 3, 1896

ASSOCIATE MEMBERS.

ALLAN, PERCY	Public Works Dept., Sydney, Australia.		April 1, 1896
BAKER, ELISHA BROWN	225-226 Lemcke Bldg., Indianapolis, Ind.		April 1, 1896
COSMUS, JOHN ALBERT	217 Orchard St., Elizabeth, N. J.		June 3, 1896
HAYES, GEORGE SAMUEL	129 West 13th St., New York City.	Jun.	Dec. 6, 1892
		Assoc. M.	June 3, 1896
HAYFORD, JOHN FILLMORE	57 So. Aurora St., Ithaca, N. Y.		May 6, 1896
HAZEN, ALLEN	85 Water St., Boston, Mass.		June 3, 1896
HENRY, FRANCIS	120 Broadway, New York City		Mar. 4, 1896
KEENE, WILLIAM FAITOUTE	Central Falls, R. I.		June 3, 1896
SCRIPTURE, ARTHUR MARQUIS	841 Genesee St., Utica, N. Y.		June 3, 1896
SPENCER, JOHN CLARK	Clinton, Iowa.		May 6, 1896
STACPOOLE, STEPHEN WISTROPP	Apartado, No. 423 Mexico City, Mexico		May 6, 1896

ASSOCIATES.

Harrison, Louis Baldwin	145 Broadway, New York City	May 5, 1896
Milne, Peter	1034 Bergen St., Brooklyn, N. Y	Jan. 7, 1896
Palmer, William Pendleton	The Rookery, Chicago, Ill	Mar. 3, 1896

JUNIORS.

Ballou, George Langdon	256 Carolina St., Buffalo, N. Y	Mar. 3, 1896
Barney, Percy Canfield	478 Waverly Ave., Brooklyn, N. Y	Mar. 3, 1896
Black, Adolph	1434 Lexington Ave., New York City	May 5, 1896
Braune, Gustave Maurice	1717 Hunter St., Harrisburg, Pa	June 2, 1896
Gridley, Vernon Hill	168 Livingston St., Brooklyn, N. Y	Feb. 4, 1896
Penfield, Walter Grant	172 Ellsworth Ave., New Haven, Conn	Mar. 3, 1896
Wulff, Adolph George	459 Riddle Road, Clifton Heights, Cincinnati, Ohio	June 2, 1896

CHANGES AND CORRECTIONS.

MEMBERS.

Adams, Arthur L	401 California St., San Francisco, Cal.
Aiken, W. A	Lock Box 686, Phœnixville, Pa.
Andrews, John W	9 Fountain Place, Kansas City, Mo.
Barlow, J. Q	Box 1077, Salt Lake City, Utah.
Bergen, Van Brunt	77th St. and Shore Road, Brooklyn, N. Y.
Bonzano, M. F	Gen. Mgr. Chattanooga R. R. Co., Chattanooga, Tenn.
Briggs, R. E	4 a Calle del Chopo, No. 3, City of Mexico.
Brown, William M., Jr	1 Mt. Vernon St., Boston, Mass.
Buck, Waldo E	Vice-Pres. Worcester Mfrs.' Mutual Ins. Co., 32 Institute Road, Worcester. Mass.
Coffin, Amory	33 East 17th St., New York City.
Collingwood, F	Avon-by-the-Sea, N. J.
Doane, Edwin A	Care of W. A. Doane, City Engr., Meadville, Pa.
Earl, George G	1405 Terpsichore St., New Orleans, La.
Eggleston, T. C	Amelia, C. H., Va.
Fiebeger, G. J	West Point, N. Y.
Fields, S. J	564 Ellicott St., Buffalo, N. Y.

FRANCIS, GEORGE B.	Res. Engr. The Boston Term. Co., 180 Summer St., Boston, Mass.
FUERTES, J. H.	277 Pearl St., New York City.
GREENE, E. A.	45 Broadway, New York City.
GREENE, B. D.	Stamford, Conn.
GOAD, CHARLES E.	15 Wellington St., West, Toronto, Can.
GUTHRIE, E. B.	Chf. Engr., Dept. Public Works, Buffalo, N. Y.
HARDING, HORACE	Birmingham, Ala.
HATCH, FRED. T.	Chief Engineer, Vandalia Line, Terre Haute, Ind.
HAZLEHURST, GEORGE B.	Catonsville, Baltimore Co., Md.
HOWE, W. B. W.	Flat Rock, N. C.
HUDSON, JOHN R.	386 Leavitt St., Chicago, Ill.
JAMESON, CHARLES D.	Gen. Mgr. Jameson & Co., Tientsin, China,
KASTL, A. E.	Div. Engr. Nashua Aqueduct, Northboro', Mass.
KING, FRANK P.	33 Clayton Block, Denver, Colo.
KNIGHT, W. H.	Care of Compressed Air Power Co., 908 Postal Tel. Bldg., New York City.
LOCKE, F. B.	North Adams, Mass.
LOW, EMILE	Cedar Bluff, Va.
LUDLOW, WILLIAM	Light House Depot, Tompkinsville, Staten Island, N. Y.
MCCURDY, JOHN E.	Supt. Helena Mining Co., Cusihuiriachic, Chihuahua, Mexico.
MCKAY, JOHN E.	1st Asst. Engr. Croton Aqueduct, 150 Nassau St., New York City.
MORLEY, FRED	Lapeer, Mich.
NOURSE, E. G.	1311 Monadnock Block, Chicago, Ill.
PRATT, WILLIAM A.	1321 Gilpin Ave., Wilmington, Del.
ROGERS, FAIRMAN	Care of Dick Bros. & Co., 423 Walnut St., Philadelphia, Pa.
RUGGLES, WILLIAM B.	Chf. Engr. C. P. & V. R. R., Carlile Bldg., Cincinnati, Ohio.
SEAMAN, HENRY B.	40 Wall St., New York City.
SIMS, A. V.	Wenonda, Pittsylvania Co., Va.
WASHBURN, F. S.	1016 Lord's Court Bldg., William St. and Exchange Place, New York City.
WELLS, CHARLES E.	Div. Engr. Met. Water Board, Northboro', Mass.
YEATMAN, POPE	Box 67, Johannesburg, South African Republic.

ASSOCIATE MEMBERS.

ADAMS, EDWIN G., Jr.	Union Bridge Co., Athens, Pa.
BAINBRIDGE, F. H.	P. O. Box 77, Jackson, Tenn.
BOWMAN, A. L.	U. S. Asst. Engr., Norfolk, Va.

CUMMINGS, R. A.	Wallingford, Delaware Co., Pa.
DAVIS, ARTHUR P.	U. S. Geological Survey, Washington, D. C.
DEWEY, EDWARD WILKINS	Room 167, 66 Broadway, New York City.
FOLWELL, A. P.	Leroy, N. Y.
FORT, EDWIN J	351 Macon St., Brooklyn, N. Y.
GAHAGAN, W. H.	Asst. Engr. C. & N. W. Ry., Lodi, Wis.
GRAVES, E. D.	Box 748, Hartford, Conn.
GRAY, EDW., Jr.	Engr.'s Office, W. Va. C. & P. Ry. Co., Cumberland, Md.
HEMMING, D. W.	100 East 80th St., New York City.
HOUSTON, JOHN J. L.	814 North 21st St , Philadelphia, Pa.
KYLE, GEORGE A.	Care of Simmer & Jack Gold Mining Co., Germinton P. O., So. African Republic.
LAWLOR, THOMAS F.	Blackstone Valley Street Ry. Co., Millbury, Mass.
LENTILHON, EUGENE	Foot of Perry St., New York City.
MITCHELL, H. H.	Box 1597, Malden, Mass.
MOORE, CHARLES H.	Asst. Engr. Erie R. R. Co., Bear Lake, Warren Co., Pa.
PARMLEY, WALTER C.	19 Burt St., Cleveland, Ohio.
STENGER, E.	Mendota, Ill.
STOUT, E. C	203 Broadway, New York City.
TUSKA, G. R.	Chf. Engr. Panama R. R. Co., 29 Broadway, New York City.
VON GEMMINGEN, S.	Nameless P. O., Campbell Co , Va.
VOORHEES, PAUL	1210 Guaranty Bldg., Buffalo, N. Y.
WHEELER, H. R.	Babcock-Lary Dredging Co., 29 Broadway, New York City.

ASSOCIATES.

ABBOTT, EDWARD L.	Care of Clark & Co., 100 Broadway, New York City.
KARNER, W. J.	Chf. Engr.'s Office, Illinois Central R. R. Co., Chicago, Ill.
KNOWLTON, THEO. E.	Watertown, N. Y.
SMITH, H. S. S.	Princeton University, Princeton, N. J.
WARDER, JOHN H.	1632 Briar Place, Chicago, Ill.

JUNIORS.

ALBERTSON, CHARLES	22 East Mt. Airy Ave., Mt. Airy, Philadelphia, Pa.
BELL, A. C.	509 Union Trust Bldg., St. Louis, Mo.
BLACK, ADOLPH	41 East 49th St., New York City.
BLODGETT, JOHN	977 Prospect St., Cleveland, Ohio.
BOGEN, L. E.	Linden Ave., Avondale, Cincinnati, Ohio.
BOYD, JAMES C.	Smyrna, Me.
CHRISTY, GEORGE L	Athens, Pa.

Clarke, T. C., Jr. ....247 Fifth Avenue, New York City.
Crane, Will E. ....40 Ambrose St., Rochester, N. Y.
Cummings, Noah. ....332 Alexander Ave., New York City.
Diebitsch, Emil. ....297 Henry St., Brooklyn, N. Y.
Ellis, D. L. ....628 First Ave., No. Minneapolis, Minn.
Folger, E. P. ....Fulton, N. Y.
Ford, William H. ....U. S. Geological Survey, Oakfield, N. Y.
Kummer, F. A. ....Box 831, Baltimore, Md.
McKenney, Charles A. ....1523 Rhode Island Ave., Washington, D. C.
Millard, Curtis ....Care of Circleville Water Supply Co., Circleville, Ohio.
Monsarrat, N. D. ....825 Dennison Ave., Columbus, Ohio.
Phillips, H. C ....Millbrook, N. Y.
Samuelson, A. B. ....17 East 115th Street, New York City.
Seltzer, Henry K. ....Care of M. P. Paret, Resident Engineer, K. C., P. & G. Ry., Lake Charles, La.
Stair, William H. ....Army Building, New York City.
Thompson, M. J. ....422 Orchard Place, La Crosse, Wis.
Todd, A. Miller ....Care of U. S. Engineer's Office, Arkansas City, Ark.
Travell, Warren B. ....116 East 17th St., New York City.
Walls, W. S. ....325 Water St., Pittsburg, Pa.
Wilkerson, T. J. ....Care of Youngstown Bridge Co., Youngstown, Ohio.
Wilson, C. W. S. ....Div. Engr.'s Office, N. Y., N. H. & H. R. R., Providence, R. I.

DEATHS.

Bliss, Henry Isaac ....Elected Member Sept. 5th, 1883; died July 10th, 1896.
Lyte, Francis Asbury ....Elected Assoc. M. Oct. 5th, 1892; died June 24th, 1896.
Stanwood, James Hugh ....Elected Assoc. M. Oct. 3d, 1894; died May 24th, 1896.
Tallon, John Joseph ....Elected Junior Sept. 3d, 1890; died May, 1896.
Wheeler, Orlando Belina ....Elected Member Nov. 2d, 1887; died June 3d, 1896.

ADDITIONS TO

LIBRARY AND MUSEUM.

From Alabama Industrial and Scientific Society, University, Ala.:
Proceedings, Vol. VI. Part 1, 1896.

From American Institute of Electrical Engineers, New York, N. Y.:
Transactions, Vol. XII.

From American Institute of Mining Engineers, New York, N. Y.:
A Mechanical Coke-Drawer.
Action of Blast-Furnace Gases upon Various Iron Ores.
Coal-Dust as an Explosive Agent.
Copper Ores in the Permian of Texas.
Eccentric Jig, with Adjustable and Automatic Lower Discharge.
Faulting and Accompanying Features Observed in Glacial Gravel and Sand in Southern Michigan.
Gold in Granite and Plutonic Rocks.
Laboratory Note on the Heat-Conductivity, Expansion and Fusibility of Fire Brick.
Middle-Product Jig.
Notes on the Walrand-Legénisel Steel Casting Process.
Rapid Section-Work in Horizontal Rocks.
The Accumulation of Amalgam on Copper Plates.
The Cycle of the Plunger-Jig.
The Monazite Districts of North and South Carolina.
The Newton-Chambers System of Saving the By-Products of Coke-Manufacture in Bee-Hive Ovens.
The Physics of Cast Iron.
The Sulphuric Acid Process of Treating Lixiviation Sulphides.
Vein-Walls.
Transactions, Vol. XXV, 1895.

From American Iron and Steel Association, Philadelphia, Pa.:
Statistics of the American and Foreign Iron Trades for 1895.

From American Society of Irrigation Engineers, Denver, Colo.
Quarterly, Vol. II, No. 2. April, 1895.

From Association of Swiss Engineers and Architects, Zurich, Switzerland:
Bauwerke der Schweiz, Heft 1.

From Onward Bates, Chicago, Ill.:
Minutes of Convention of Employes, Bridge and Building Department, Chicago, Milwaukee and St. Paul Railway, January 14th and 15th, 1896.

From G. H. Benzenberg, Milwaukee, Wis.:
Annual Report of the Board of Public Works, Milwaukee, Wis., for the year ending December 31st, 1895.

From W. G. Berg, New York, N. Y.:
Proceedings of Second, Third and Fourth Annual Meetings of the American International Association of Railway Superintendents of Bridges and Buildings. 1892, 1893 and 1894.
Constitution and By-Laws and Directory of Members of the Association of Railway Superintendents of Bridges and Buildings.

From G. W. Birdsall, New York, N. Y.:
Reports of Department of Public Works of the City of New York for 1886.

From Board of State Engineers of Louisiana, New Orleans, La.:
Report from April 20th, 1894, to April 20th, 1896.

From Board of Trustees of the Sanitary District of Chicago:
Proceedings April 15th, 22d, 29th, and May 4th, 13th, 27th and 29th, June 10th and 24th, July 1st, 8th, 22d, 1896

From Boston Public Library, Boston, Mass.:
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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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PAPERS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CONTENTS:

THE SUSPENSION OF SOLIDS IN FLOWING WATER.

By Elon Huntington Hooker, Ph. D.

To be Presented September 2d, 1896.

Considerable space in this paper is devoted to the historical side of the subject because the sources of information are widely scattered, and it is desired to indicate, so far as possible, the origin of the ideas and observations upon sedimentary movements which have become common knowledge. In the second part of the paper a comparison of particular facts and observations leads to certain general conclusions with reference to the manifestation of the phenomena studied. The concluding portion is devoted to an analysis of the different explanations of the cause of suspension, for the purpose of building up a satisfactory theory.

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

To conduce to uniformity and clearness, the following symbols will be used throughout this discussion :

g = 32.2 ft. per second = acceleration of gravity.
F = area of right section of body considered.
h = head of water corresponding to the velocity v.
v = mean velocity of the stream in the vertical considered.
v_1 = surface velocity at the vertical considered.
v_0 = bottom velocity at the vertical considered.
i = inclination of the water surface.
f' = tangent of the angle of sliding friction.
f = tangent of the angle of rolling friction (properly a distance).
γ = heaviness of the liquid considered. For the purposes of this article, $\gamma = 62.5$ lbs. per cubic foot = heaviness of fresh water.
γ' = heaviness of the solid considered.
P = resultant thrust, in the stream direction, exerted by a moving liquid upon a solid.
V = volume.
G = weight.
M = mass.
k = constant determined by experiment.
Z = mean depth of stream.
z = variable depth below surface.
b = width of stream.
r = radius of sphere.
q = liquid discharge per unit width of stream.
d = solid discharge per unit of width.

Part I.—Historical Development of the Problem[1].

The varied phenomena incident to the flow of rivers have demanded the consideration and even the anxiety of riparian owners from a time far antedating the development of the modern science of hydraulics. Wherever rugged slopes discharge their melted snows or heavy rains are gathered from steep, impervious water-sheds, a mountain torrent has its birth, and the householder in the valley early learned to study its varying humors. The rapid descent of the Apennines to the sea

[1] It is proposed here to select, from the mass of literature touching upon this problem, only those discussions and observations which seem to mark a distinct step toward its final scientific solution.

and the consequent turbulent character of the streams of northern Italy, made this a fruitful field of study to a people whose scientific spirit had already gone far toward establishing the fundamental laws of fluid motion.

During the latter part of the seventeenth century means were sought for the amelioration of these mountain rivers. Dominique Guglielmini, physician and hydraulician, was employed by Venice and other Italian cities to prepare plans looking toward the prevention of their ravages. His greatest work was the building of the levees on the Po above Plaisance, and his writings[1] gave the first impetus to a scientific study of fluvial phenomena.

In 1773 Johann Silberschlag produced his comprehensive treatise on hydraulics[2], covering this field to some extent, but it was left to Dubuat[3] in 1786 to publish the first experimental studies which can be considered authoritative. These experiments were made at Paris by order of the French government. His determination of the different velocities at which solid particles begin to be moved by flowing water has been accepted by subsequent writers, and with his work begins the scientific knowledge of the movement of alluvions in sedimentary rivers.

Dubuat's artificial canal was formed of planks 12 pieds[4] in length, 3 pouces thick and 18 pouces wide, so fitted that the form could be altered from rectangular to trapezoidal by the addition of supplementary bracing. Its total length was 132 pieds, and in the trapezoidal form it had a clear bottom width of $5\frac{3}{4}$ pouces to a surface width of 3 pieds. Water was discharged into the canal under a maximum head of 7 to 8 pieds.

Surface velocities were measured with floats, noting the time of traversing 10 toises[4]. For determining bottom velocities a small ball of mastic was first adopted. Its specific gravity was such that it lost $\frac{13}{14}$ of its weight in water, and was thus very easily moved. Later, more satisfactory results were obtained with red currants. These were

[1] "Della natura di fiumi trattato fisico matematico." Guglielmini, Bologna, 1697.

[2] "Hydrotechnik oder des Wasserbaues." Johann Silberschlag, Leipzig, 1773. Copy at Zurich Polytechnikum.

[3] "Traité d'Hydraulique." Dubuat, Paris, 1786. Page 57, Volume I. Third edition published in 1816. Copy at Zurich Polytechnikum and at École des Ponts et Chaussées, Paris.

[4] "Système ancien" of France—

1 pouce = 1.066 ins.
1 pied = 1.066 ft.
1 toise = 6.395 ft.

These units were in use previous to 1812. Between 1812 and 1840 the "système usuel" was in vogue. Its values are slightly larger—1 pouce = 1.093 ins.

smoother, moving with less friction, and could be more easily seen. The time of passing through a distance of 60 pieds was noted.

The bottom velocities at which various materials began to be moved by the current were as follows:

Potter's clay (beginning with a velocity of 45 pouces, it continued to be carried away as the velocity was gradually decreased to 7 pouces. At 7 pouces a deposit of fine sand took place, which continued on down through a velocity of 4 pouces, until at 3 pouces per second the clay ceased to show action)	3 pouces per second.
Gravel (size of anise seed)	4 pouces.
Gravel (size of peas)	7 "
Coarse sand (sand remained stable while bottom velocity was increased from 3 up to 7 pouces. At 8 pouces it began to be entrained and for velocities of 12 to 45 pouces per second it continued to be entrained and suspended)	8 "
Sea pebbles (1 pouce diameter)	24 "

Dubuat's experiments also showed that a current velocity of 10 or 12 pouces per second was sufficient to produce sand waves in a bottom whose grains were large enough to be easily visible. He describes these furrows as perpendicular to the longitudinal axis of the current with a short steep down-stream face and a long gentle posterior slope. Each sand grain was slowly rolled along the up-stream incline and fell of its own weight down the crest, thus advancing the wave by steps equal to the diameter of the grains.[1] He computes a velocity under these circumstances which requires two years to cover a length of 2 400 toises.

The expression now universally used to represent the thrust exerted by a current against a solid of any form was deduced by Dubuat[2] and the coefficients experimentally determined.

He argued that the pressure on the up-stream face (p_1) would be greater and that on the down-stream face (p_2) would be less than the

[1] For a similar description see "Report of Chief of Engineers, U. S. A.," 1875, II, pp. 502–504.
Also "Handbuch der Wasserbaukunst." G. Hagen, 1871, Zweiter Theil, "Die Ströme," S. 161–162.

[2] See Flamant, "Hydraulique," 1891, p. 561.

pressure (p) at the corresponding points if the solid were removed. Therefore, the total impelling force would be

$$P = F(p_1 - p_2) = F[(p_1 - p) + (p - p_2)].$$

These pressures can be written as functions of the velocity height h, whence

$$\frac{p_1 - p}{\gamma} = m\frac{v^2}{2g} \text{ and } \frac{p - p_2}{\gamma} = n\frac{v^2}{2g},$$

when m and n are experimentally determined.

By substitution,

$$P = (m + n)\,\gamma\, F\frac{v^2}{2g} \text{ or, as usually written,}$$

$$P = k\,\gamma\, F\cdot\frac{v^2}{2g}.$$

The fact that floating solids move with a velocity superior to that of the current which bears them was noted by Dubuat[1]. His explanation of it was inaccurate, but the phenomenon itself has an important bearing on the present discussion.

Of interest in this connection is the experimenter's statement with reference to the theoretical form of bed best adopted for flowing streams. He rejects the rectangle and semicircle as being unable to sustain their own weight in soft soils and chooses the trapezoidal cross-section as offering a proper talus. These right lines will be rounded by the stream itself, the slope being proportioned to the diminishing velocity from center to sides.[2]

Dubuat's work further includes various studies into the régime of rivers and the development of rules for that radius of curvature at bends which will best conduce to stability. To him belongs the honor of inception along these lines.

J. A. Fabre was the next to publish systematic studies[3] on the movements of solids in torrents and rivers, followed in 1811 by the voluminous encyclopedia of Wiebeking.[4] These men extended the range of observed data without making material additions to the theory of fluvial action.

In the year 1845, Bouniceau[5] discussed at considerable length the

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1 "Principes d'Hydraulique," Dubuat, No. 220. Quoted by Durand-Claye, *Annales des Ponts et Chaussées*, 1886, 1, 530.

2 See "Principes d'Hydraulique," Dubuat, 1786, Vol. I, p. 119.

3 "Essai sur la theórie des torrents et des rivières," J. A. Fabre, Paris, 1797, Première Partie.

4 "Wasserbau" C. F. Wiebeking, Munich, 1811-1817, 4 volumes.

5 "Étude sur la navigation des rivières à marées et la conquête de lois et relais de leur embouchure." Bouniceau, Paris, 1845.

shifting of sands in tidal estuaries, and showed himself a close student of the laws of erosion by water action. His excellent little volume brings to light and discusses a number of anomalies in this form of action.

He gives a set of values of the bottom velocities at which erosion begins to take place with different materials :[1]

Clay	0.08 — 0.15	m. per second.
Coarse sand	0.22 — 0.30	"
Coarse gravel	0.11 — 0.61	"
Ordinary pebbles	0.65 — 1.00	"
Stones (size of an egg)	1.00 — 1.20	"
Conglomerates	1.52	"
Sedimentary rock	1.83	"
Solid rock	3.00	"

The River Garonne for a length of 45 miles below the embouchure of the Lot was made the object of a series of observations covering 11 years by M. Baumgarten.[2] These measurements deal with the varying discharges from month to month, with the constant changes in form of cross-section and maximum depths, determinations of the fall and heights of water as well as with geological and meteorological studies of the valley. It has formed the model for later fluviatile studies. Here are given the first measurements of discharge of detritus[3] which the author has been able to find. Daily samples were taken at Marmande from the surface of the river in a vessel containing 4.6 liters. This was allowed to stand for nine or ten days, the clear water decanted and the sediment filtered until thoroughly dry. After weighing, a simple calculation gave the weight in grams of mud per cubic meter of water. These measurements were continued from 1839 to 1846 continuously, and the average monthly solid discharge of the river at this point computed.[4] M. Baumgarten distinguishes three different methods of movement common to these solids.

[1] "Etude sur la Navigation," etc., p. 19.

[2] "Navigation fluviale, Garonne." M. Baumgarten, Ingénieur ordinaire. *Annales des Ponts et Chaussées*, 1848, 2, 1-157.

[3] Same, pp. 47, 146.

[4] In order to see if the water contained the same amount of suspended matter at all depths, Baumgarten made a series of tests of specimens from different depths and taken from points where the velocity was different.

From the results given in the table in the continuation of this note on the opposite page he decided that a surface specimen gave a fair average.

First.—A discontinuous rolling motion along the bed of the stream which takes place when the velocity of the current is limited or the materials large.

Second.—With greater velocities or smaller particles, a discontinuous suspension in the lower laminæ of the current.

Third.—Movement in continuous suspension when the particles are carried throughout the entire length considered.

The sand waves which M. Dubuat had observed on a small scale are reproduced in the Garonne on a large scale in gravel shoals, and M. Baumgarten made careful measurements of the yearly progress of one of these crests.

In 1840 the talus down stream had a vertical height of 1.3 m., a base of 2.8 m., while the length of the crest was 180 m. In 1841, the form was nearly the same, but the crest had moved down stream parallel to itself about 30 m. In 1842 the forward motion was 20 m. These gravels were of about the size of a walnut, and the velocity of the water averaged 2.25 m. per second.

Thus far attention had been especially directed towards the phenomenon of dragging, and the laws it follows had been, to some extent, investigated. Inspecteur-Général Dupuit,[1] in 1848, emphasized the true importance of suspension in the movements of soft river bottoms, and to him is due the first scientific study of the causes which produce this action.

DATES.	Depth at which the water was taken.	WEIGHT OF FILTERED SEDIMENT.	
		In dead water of a bridge or in a gentle current.	In a strong current.
		Grams.	Grams.
March 25th, 1847..	at the bottom at 7.0 m....	0.72	....
	at 3.5 m..................	0.75	....
	at the surface............	0.82	....
March 27th, 1847..	at the bottom at 8.0 m....	0.34	....
	at 4.0 m..................	0.32	....
	at the surface	0.19	....
April 9th, 1847....	at the bottom at 8.75 m...	1.29	0.93
	at 4.40 m.................	1.43	1.18
	at the surface......	1.13	1.22
April 15th, 1847....	at the bottom at 9.0 m....	1.89	1.90
	at 4.50 m.................	1.78	2.15
	at the surface............	....	1.60
April 18th, 1847 ...	at the bottom at 8.0 m....	0.94	0.90
	at 4.00 m.................	0.87	0.68
	at the surface............	1.33	0.87

[1] "Etudes théoriques et pratiques sur le mouvement des eaux." Paris, 1848. Second edition, Paris, 1863, pp. 214–229. J. Dupuit, Inspecteur-Général.

Dupuit calls attention to the experiment of revolving rapidly a glass of water containing sand grains. He notes that there is a direct relation between the velocity of the water and the amount of sand in suspension, and that the grains tend to arrange themselves in successive laminæ according to the order of their size; as the velocity is decreased, they descend successively to the lower strata. These facts had all been observed before his time, but Dupuit goes farther than his predecessors in noting that the maximum amount of suspension, *i. e.*, that in the lower layers, corresponds, not to the greatest absolute velocity of the current, but to the maximum relative velocity of contiguous molecules. This is a distinct step in advance. Dupuit finds here his explanation of the phenomenon of suspension.

Starting with the fact first noted by Dubuat that the velocity of a float exceeds that of the current,[1] he calls attention to the tendency of such bodies to move toward the filaments of greatest velocity and explains this upon the principle of least work. Assuming the resistance to its motion to vary with the direction of its path, this direction will necessarily be that which offers the least resistance. Therefore an oblique path toward the most rapid current in the stream line will result, since this will offer the least difference in velocity between the solid and the fluid and so the least frictional work.

Dupuit derives a law for this lateral movement as follows:

Let v = the absolute longitudinal velocity of the body.
u = the absolute transverse velocity of the body.
w = absolute velocity of filament at shore side of body.
w' = absolute velocity of neighboring filament toward center of stream.

The relative velocity of the body as regards the liquid surrounding it may be expressed by:

$$\sqrt{u^2 + v^2} - \frac{w + w'}{2} \quad \text{.......................(1)}$$

Considering the resultant of the resistances which the body suffers as approximately proportional to this relative velocity, the value of u may be found for which this resultant is a minimum.

Calling Q the angle of inclination of the tangent to the curve of velocities at the point considered,

$$w' = w + u \tan. Q \quad \text{.......................(2)}$$

[1] Dupuit, in common with Dubuat, ascribes this excess of velocity to the accelerating force represented by the component of the bodies' weight parallel to the surface of the current. M. Du Boys, *Annales des Ponts et Chaussées*, 1886, 1, 199-242, has clearly demonstrated the incorrectness of this explanation.

Substituting (2) in (1) and putting the first differential coefficient of the expression equal to zero, he finds that the resistance will be a minimum for

$$u = \frac{\tan. Q}{2} \sqrt{u^2 + v^2}$$

i. e., the transverse velocity should decrease with the tangent of the curve of surface velocities, or, in other words, from the banks to the center of the stream. This is equivalent to saying that the maximum lateral velocity will correspond to the maximum relative velocity of the filaments.[1]

Applying this same law to the velocities considered in a longitudinal section, he finds a resultant force acting obliquely upward, which produces the phenomenon of suspension. As this force will be greatest where the relative velocities are greatest, *i. e.*, near the bottom, the lower laminæ will carry the heavier load of particles. Solids of equal density will arrange themselves from bed to surface in the order of their volume. Suppose, now, the relation of a solid to neighboring ones is considered. The presence of another will tend to decrease the relative velocities of the filaments, and so the two will be obliged to descend to a lower lamina than would the one alone. Descent or ascent will follow according as the bodies approach each other or separate.

Dupuit formulates these laws as follows:

"*First.*—A water current can suspend solids of a density superior to its own.

"*Second.*—The power of suspension depends upon the relative velocity of the filaments and is greater according as this relative velocity is greater. In general, it is proportional to the quantity $\frac{dv}{dz}$ (where v = velocity of current and z = depth below surface) so that lower layers can carry either more solids or those of greater volume.

"*Third.*—The power of suspension of a bed is limited, *i. e.*, a square meter of cross-section can only carry a certain number of solids of a definite volume. Thus each lamina has a different degree of saturation."

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[1] Observations made by Major Cunningham in the Ganges Canal seemed to indicate a current from the shore to mid-stream whose intensity followed this same law (see *Proceedings* of the Institution of Civil Engineers, Vol. LXXI, p. 66). As this current was indicated only by the behavior of certain floats, it is more in consonance with present knowledge to believe their action due to the cause given here by Dupuit than to suppose an actual lateral motion of the water.

Dupuit assumes a river flowing with section and fall unchanged, and saturated with sediment. The entire load will be carried to the embouchure. Suppose the section to vary. At each change will come a change in the curve of velocities and a consequent change in the power of suspension.

When this power is reduced, there will follow a deposit, and when it is increased, erosion will take place. He makes it clear also that these results are dependent, not only upon the section at the point where the change takes place, but also upon the anterior portion of the river as affecting the state of saturation in which the river reaches the section in question. These effects can be brought about at any point whatever by suitably changing the up-stream section.

When a deposit occurs the material comes wholly from the lower laminæ, and they, in turn, receive from the upper ones the material in excess of their power of suspension. This explains the lamination of river-beds in materials increasing in size with depth below the bottom. The frequent presence of beds of finer particles interrupting this structure he explains by the principle that saturation may be obtained either by the size of the particles or by their nearness together.

The numerous variations to which this laminated movement is subject is noticed, and explains the constant rising and falling of particles from one lamina to another, while the nature of the horizontal curve of velocities is such as to cause a constant movement of particles from the banks toward the center. To this may be attributed the tendency of a river to form islands in the middle of its bed at the expense of its banks.

Among the German writers of this period, the discussion of the transportation of stones by torrents was especially taken up by Joseph von Gumppenberg Pöttmes[1], but no further experiments were published until 1857, when Blackwell[2], in England, extended the investigations of Dubuat to solids of larger dimensions.

The velocities given in the table on the next page are those at which movement began:

[1] "Der Wasserbau an Gebirgsflüssen," Joseph Freiherrn von Gumppenberg Pöttmes, Augsburg, 1854.

[2] See "Report of the Referees upon the Main Drainage of the Metropolis," July 31st, 1857, Appendix IV. Also, for table here quoted, see *Proceedings* of the Institution of Civil Engineers, Vol. 82, p. 48.

Description of substance.	Cubic Contents.		Velocities.		Increase of contents of substances moved.	Increase of velocities.	Sixth root of increase of contents.
	1. Cubic inches.	2. Cubic inches.	1. Feet per second.	2. Feet per second.			
Brickbats........	2.59	18.5	1.75 to 2.00	2.75 to 3.00	7.14	1.37 to 1.70	1.38
Brickbats........	4.76	18.5	2.25 to 2.50	2.75 to 3.00	3.97	1.10 to 1.33	1.26
Oolites...........	2.39	17.68	2.00 to 2.25	2.75 to 3.00	7.40	1.22 to 1.50	1.39
Flints............	1.95	10.37	2.50 to 2.75	3.00 to 3.25	5.32	1.09 to 1.30	1.32
Slate.............	2.38	9.06	2.00 to 2 25	2.75 to 3.00	3.81	1.22 to 1.50	1.25

The important idea of saturation with solid material is definitely stated[1] by M. Scipion Gras in a valuable paper[2] published at this time.

He defines saturation in a stream as that state at which the least addition to the solid material already carried will cause a deposit, and its power of entrainment as the total weight of material which a given stream in a state of saturation can carry. He assumes this power of transport to vary directly with the velocity, density and depth of the water, and, these quantities remaining constant, to vary with the volume, density and form of the solids submitted to its action. Upon these principles he explains erosion as a necessary consequence, when the saturation corresponding to the actual velocity is incomplete, unless the bed offers too great a resistance.

Measurements of the advance of the crests of shoals, similar to those undertaken by Baumgarten in 1840, were made by Hübbe[3] in 1861 on sand bars. His observations show the same wave form on a large scale, which Dubuat had noticed in the minute form, and confirm Baumgarten's statement of the forward motion of the crests.

The results of the exhaustive study of the Mississippi River[4] and

[1] Probably first stated by Frisi, "On Rivers and Torrents," 1732. See Report on Mississippi River. Humphreys & Abbot, pp. 190, 415.

[2] "Études sur le torrents des Alpes." M. Scipion Gras, *Annales des Ponts et Chaussées*, 1857, 2, pp. 1–96.

[3] *Zeitschrift für Bauwesen*, Jahrgang xi, 1861. Abstracted in *Zeitschrift des Architekten und Ingenieur-Vereins*, Hanover, 1863, p. 518.

[4] "Report on the Mississippi River." Humphreys and Abbot, 1861. Reprinted with additions, Washington, 1876.

its delta were published in 1861, and contain a wide range of data on the distribution of sediment. Observations along the same lines as those of Baumgarten were instituted at Carrollton in 1851, and lasted throughout two years. They were conducted by Prof. Forshey. Samples were taken from a point near the east bank, where the high-water depth was 100 ft., from the middle of the river, and from a point near the west bank, where the high-water depths were 100 and 40 ft., respectively. These tests were made daily (except Sundays) and samples taken from surface, mid-depth and bottom by means of a small weighted keg, with valves opening upward, which was designed to allow free passage to the water until it reached the desired depth. At the station near the west bank only surface and bottom samples were taken. An average value was obtained for the weight in grams of sediment to 600 grs. of water at each of the positions, 100 grs. of the water being measured out into its proper precipitating bottle for each of the six working days of the week, and corresponding to each of the eight positions.

During the second year samples were taken only from the surface and at the position near the east bank. The tabulated results of these measurements are given in Humphreys and Abbot's Report (edition of 1876, pp. 134, 417).

From the study of these results, Humphreys and Abbot drew the following conclusions:

"This table is fruitful in results. It establishes that the Mississippi water is not charged to its maximum capacity with sediment, because the distribution of the material is different from what must have place were this the case. Dupuit demonstrates that the power of suspension is due to the fact that the different layers of water are actuated by different velocities, and thus exert different pressures upon the different sides of the suspended atoms. Hence, the greater the difference in the velocity of consecutive layers, the greater will be the power of suspension. Now, it is conclusively proved in Chapter IV[1] that the change of velocity from layer to layer is, in horizontal planes, greatest near the banks and the least near the thread of the current; and in vertical planes, parallel to the current, the greatest near the bottom and surface, and the least at a point about 0.3 of the depth below the surface, where the absolute velocity has its maximum value. If, then, the water be either charged to its maximum capacity or overcharged with sediment, we must find the greatest amount near the banks and

[1] "Report on the Mississippi River." Humphreys and Abbot.

near the surface and bottom, and the least amount near the thread of the current and near the layer 0.3 of the depth below the surface. If the water be undercharged, on the contrary, the distribution of sediment will follow no law, the amount at any point being fixed by the accidental circumstances of whirls, boils, etc., although, of course, there will be an accumulation of material near the bottom, where the suspending power is very much greater than elsewhere. Bearing these well-established principles in mind, an inspection of the preceding table must convince any one that the Mississippi water is undercharged with sediment, even in the low-water stage. A most important practical deduction may be drawn from this fact, namely, the error of the popular idea that a slight artificial retardation of the current, that caused by a crevasse, for instance, must produce a deposit in the channel of the river below it."

Sediment observations were also made at Columbus by the Mississippi survey from March to November, 1858, but, as only surface specimens were taken and no tabulated results give a means of comparison between the amounts in suspension near the banks and at the thread of the current, they can be of little service in the scientific study of the distribution of sediment in the cross-section of the river. Curves are shown, however, on Plates XII and XIII of their Report,[1] from which the relation between the mean velocity of the river and the corresponding mean amount of suspended matter at Carrollton and Columbus may be seen. The values from which these curves are plotted are given at page 417 of the same Report (edition of 1876).

From them Humphreys and Abbot are led to the same conclusion as before, *i. e.*, that the Mississippi water is not saturated with sediment, using the term in the sense in which it is used by M. Scipion Gras.[2]

Their line of reasoning is as follows: If the water be at all times charged with sediment to the maximum capacity allowed by its velocity, then the amount of sediment at different stages must vary proportionately with the mean velocity.

"At the date of highest water, both in 1851 and 1858, the river held in suspension but little more sediment per cubic foot than at dead low water. * * * Moreover, it will be seen that an analysis of the distribution of sedimentary matter held in suspension leads to the same

[1] "Report on the Mississippi River." Humphreys and Abbot.

[2] See page 363.

conclusion, by establishing that the river is never charged to its maximum capacity of suspension."

Extreme care was taken in all these measurements in determining the amount of sediment in the sample obtained. It was shown that determinations of sediment must be made by weight and not by volume, as the latter method introduced discrepancies. These were due to the difference in density of the sediment, resulting from different methods of manipulation by various observers.

An extended series of measurements had been in progress on the Elbe, at Harburg, during the years 1837 to 1855, by Baurath Blohm.[1] The data obtained were minutely examined and formed the nucleus for a work treating of the subject in all its bearings. The early death of Herr Blohm prevented the publication of anything but the introductory part of the proposed book. Reference will be made to these observations later.

In 1871, M. Partiot published studies[2] on the movement of sands in the Loire, and enriched the knowledge of the subject by minute observations and extensive measurements. This monograph deserves especial mention, as it brings out strongly the importance of vortices and eddies in the suspending power of water.

Attention is called to the interaction of the suspended particles in changing their forms by friction, to the suspension and disintegration of the clays in the higher layers and their mixture with vegetable matter to form the rich alluvial deposits which settle on the summit of the shoals at the embouchure of the Loire. The slower moving sands are carried only intermittently in suspension.

Measurements are given to show that the quantities of sediment decrease toward the river mouth, and the interesting point is determined by experiment that the amount of silt varies not only with the height of the flood, with reference to others, but also with its own relative state. Increasing as the flood crest approaches, it reaches a maximum at its summit and descends to a lower point at the middle of the posterior slope than at the corresponding point of the anterior slope.

Partiot emphasizes the idea that the sands are only sustained by

[1] "Ueber die in fliessenden Wasser suspendirt erhaltenen Sinkstoffe." *Zeitschrift des Architekten und Ingenieur Vereins*, Hanover, 1867, pp. 240–297.

[2] "Mémoire sur les Sables de la Loire." M. Partiot. *Annales des Ponts et Chaussées*, I, 1871.

eddies and vortices. He refers to experiments made at Nantes in 1869. Samples were taken at different depths at a point where the river was straight and free from eddies. Sand was not found in suspension, though when introduced 60 ft. above, in a surface velocity of 1.4 ft. per second, its presence was readily detected. At another point, where there was a marked eddy, grains of sand and mica were seen to surge to the surface and glitter in the sunlight, while grains of quartz were brought up in the receptacle from all depths. When the vortices were rapid, grains could even be taken in the hand.

The production of these vortices and eddies is attributed to the inequalities of the bottom, the solids deposited there, the deflecting action of concave banks and the action of floods. As the flood moves down a river in the form of an attenuated wave, the water flows down the front incline with an accelerated velocity. It overtakes the surface water down stream and flows over it, causing eddies. These grow greater as the crest of the wave is approached, since the fall increases, reach a maximum at the summit and decrease on the posterior portion, where the fall is decreased. This view is corroborated by the corresponding measurements of sediment in suspension.

The great velocities which these vortices reach in time of flood explain the movement of boulders, which could not be taken up by ordinary waters. M. Partiot calls to mind the lifting strength of whirlwinds as a parallel case. An interesting point is brought up in the reference to the action of ice in the movement of these solids. The sand grains and pebbles, as well as large stones, at times become frozen into the ice forming at the bed and banks of streams. With the least rise in the water this may become detached and carried to great distances.

It is to dragging rather than suspension that Partiot attributes the motion of sands in the Loire, and quotes some valuable researches made by M. Sainjon in this connection.

A body immersed in a moving liquid is subjected by the current to a thrust which may be expressed by

$$k \gamma F h = k \gamma F \frac{v^2}{2g}.$$

M. Sainjon takes the constant $k = 1.46$ for a prism, and $k = .60$ for a sphere, or as an average $k = 1$ for the particles making up gravels.

The action of gravity upon this immersed body tending to roll it down stream is put equal to

$$(\gamma' - \gamma)\ V \left(\frac{i}{\sqrt{1+i^2}} - f \right)^{1}$$

Since i rarely reaches the value $\frac{1}{10}$ it is neglected and the approximate expression becomes

$$- V(\gamma' - \gamma) f,$$

whence the resultant force in the direction of the current becomes

$$P = \gamma\ F\ \frac{v^2}{2g} - V(\gamma' - \gamma) f$$

assuming $k = 1$.

To determine the value of f, M. Sainjon uses the results of the experiments of Dubuat. In this case the bottom velocities were determined at which the various materials ceased to be moved by the current[2], and at this point he considers that the approximate resultant force obtained above may be put = o, *i. e.*,

$$\gamma\ F \frac{v^2}{2g} - V(\gamma' - \gamma) f = 0,$$

whence

$$f \frac{V}{F} (\gamma' - \gamma) = \gamma \frac{v^2}{2g},$$

---

[1] This value is inexact. The correct value is derived as follows:

Represent the resultant weight in water of the body rolling down the inclined river-bed by $W = V(\gamma' - \gamma)$. Let β = the angle of the inclination of the bed.

The gravity component parallel to the bed $= W \sin.\ \beta$ .... (1)

The normal component of $W = N = W \cos.\ \beta$.

The rolling friction $= F = N \tan.\ Q = W \cos.\ \beta \tan.\ Q$ .... (2)

Therefore the resultant force acting is:

$$W \sin.\ \beta - W \cos.\ \beta \tan.\ Q.$$

or since $\tan.\ \beta = i$ and $\tan.\ Q = f$, this becomes

$$V(\gamma' - \gamma) \left(\frac{\tan.\ \beta}{\sec.\ \beta} - \cos.\ \beta \tan.\ Q \right) = V(\gamma' - \gamma) \left(\frac{\tan.\ \beta}{\sqrt{1 + \tan.^2 \beta}} - \cos.\ \beta \tan.\ Q \right)$$

$$= V(\gamma' - \gamma) \left(\frac{i}{\sqrt{1+i^2}} - f \cos.\ \beta \right).$$

By neglecting i, however, thereby virtually putting $\beta = 0$, this final expression reduces to the same form as M. Sainjon's approximate expression $- V(\gamma' - \gamma) f$ which is the one used. Therefore no results are vitiated.

[2] Sainjon is so quoted by Partiot ("Sables de la Loire," p. 32). In one case, at least, that of large sand, Dubuat states ("Traité d'Hydraulique," Paris, 1786, p. 94) that the velocity given is that at which the sand began to be moved as the bottom velocities were increased gradually from 3 up to 8 pouces per second.

These results are tabulated as follows:

Kind of material.	Bottom velocity of current. Meters per second.	$\frac{v^2}{2g}$	$\gamma' - \gamma$	$\frac{V}{F}$	$\frac{V}{F}(\gamma' - \gamma)$	$\gamma \frac{v^2}{2g}$	f
Dark potter's clay........	0.081	0.0003	1.64	....	....	......	....
Sand deposited by this clay.....	0.162	0.0013	....	....	....	......	....
Coarse sharp yellow sand.	0.216	0.0024	1.36	0.002	0.0027	0.0024	0.88
Seine gravels. Size of anise seed........	0.108	0.0006	1.545	0.001	0.0015	0.0006	0.40
Seine gravels. Size of peas...	0.189	0.0018	1.545	0.003	0.0046	0.0019	0.41
Seine gravels. Size of small beans.......	0.325	0.0054	1.545	0.0045	0.0069	0.0054	0.78
Rounded sea pebbles of an inch or more diameter.....................	0.650	0.0215	1.614	0.018	0.0291	0.0215	0.74
Angular flints (size of a hen's egg).............	0.975	0.0484	1.250	0.045	0.0562	0.0484	0.86

The mean value of f is 0.68. Eliminating the two values, 0.40 and 0.41, so widely different from the others, the mean would be 0.80. Since 0.68 is approximately the tangent of the slope of a natural talus of ordinary earth, while wet sand and earth should have a greater cohesion, M. Sainjon chooses to use the value $f = 0.80$.

Taking the ratio of the bottom velocity in the Loire to the mean velocity at 0.7 (determined by measurements with a Woltmann's wheel), and assuming in general $\gamma' - \gamma = 1.50$, while $\frac{V}{F}$ equals two-thirds of the diameter for round forms and equals the diameter for angular ones, he computes the following table of velocity limits above which gravels will begin to be dragged.

Size of gravel. Diameter in meters.	Velocity at bottom. Meters per second.	Mean velocity. Meters per second.
0.0025	0.25	0.36
0.01	0.50	0.70
0.04	1.00	1.43
0.10	1.50	2.14
0.17	2.00	2.86
0.38	3.00	4.29
0.67	4.00	5.21

M. C. Lechalas published a memoir,[1] also in 1871, in which he takes exception to the theory attributing suspension to the phenomenon of relative velocities. He urges that this assumes flow in parallel fila-

[1] "Les rivières à fond de sable." *Annales des Ponts et Chaussées*, 1871. Published also, after revision, as an annex to Guillemain's "Navigation Intérieure—Rivières et Canaux." Tome I. Paris, 1885.

ments which corresponds in no wise to movements under great velocities. His explanation attributes suspension to repeated shocks from the molecules of water moving more rapidly than the suspended body and to the action of eddies caused by the banks and bottom. He also calls attention to the fact that the variations in velocity in large rivers are much more rapid in the vertical than in the horizontal direction. To these rapid vertical variations he attributes the formation of some horizontal vortices.

The body of this valuable paper is devoted to an attempt to derive numerical results for the values of the mean depth, mean velocity and fall, in alluvial rivers, which will follow the contraction of its width, throughout a given length, by training walls. Certain parts, however, of M. Lechalas' work have a direct bearing on the relations between velocity and movement of sedimentary matter. It will be seen that he lays stress on the distinction between transportation by dragging and by suspension.

Referring to Dubuat's experiments, he expresses the excess of pressure on the up-stream face of an immersed body as proportional to the square of the velocity of the water surrounding the body, *i. e.*, for sand grains on a river bed,

$$\text{Thrust of the moving water} = a^1 \, v_o^2,$$

where a is a constant which varies with the dimensions, form and position of the grains of sand.

The resisting force of the sands of the Loire is put equal to $a \; 0.25^2$ since they are not transported until the bottom velocity reaches 0.25 meter.[2]

The resultant force—

$$P = a\,(v_o^2 - 0.25^2)$$

is put equal to the mass of the particle multiplied by its acceleration[3] parallel to the direction of v_o. Measuring the velocity v_o in the direction of the axis of the river, M. Lechalas considers this resultant

[1] $a\,v_o^2$ corresponds to the expression $\frac{k\,\gamma\,F}{2\,g}\,v^2$ used by M. Partiot, quoted on page 367.

[2] Compare table quoted from Sainjon at page 369. This refers to sands not already compacted by the continued action of currents of velocity too slight to transport the grains, but yet sufficient to increase the resisting power of the surface lamina.

[3] M. Lechalas has used the word *vitesse* here. It must, however, be meant for acceleration.—See "Navigation Intérieure," Guillemain, Annexes—Rivières à fond de sable, p. 489.

force proportional to the discharge of sand in the river and puts—

$$a\,(v_o^2 - 0.25^2) = b\,d$$

or

$$d = \frac{a}{b}\,(v_o^2 - 0.25^2) = m\,(v_o^2 - 0.25^2) = m\,(v_o^2 - 0.06)$$

where d represents the discharge of sand per unit of width.

The value of m is to be determined by observation, and in this way a correction made for the use of v_o, the absolute velocity of the water at the bed, instead of the relative velocity of the water and the solid particle. When the velocity v_o becomes greater than a certain value, the particles are lifted and cease to roll on the bottom. The term $-\,m\,0.06$ then disappears and

$$d = m\,v_o^2$$

for particles suspended immediately above the bottom.

The advancement of the crests of the sand bars measured by M. Sainjon in the Loire gives a method of determining the value of d for corresponding values of surface velocity v_1, and also a means of comparing this advancement with the corresponding velocities of the current v_o at the bottom.

TABLE OF OBSERVATIONS ON ADVANCEMENT OF CRESTS OF SAND BARS.

Observed surface velocity in meters per second.	Height in meters of the crest above the down-stream bed.	DISPLACEMENT OF THE CREST IN HUNDRED-THOUSANDTHS OF A METER PER SECOND.	
		Observed for a lapse of many days.	Computed.
0 58	0.900	3.0	3.0
0.64	0.300	3.3	3.9
0.73	......	5.1	5.5
0.75	0.782	6.3	5.9
0.81	0.967	6.7	7.1
0.81	......	7 5	7.1
0.83	0.760	7.6	7.5
1 00	0.953	10.5	11.6
1.016	0.920	12.4	12.0
1.016	0.580	12.0	12.0
1 03*	0.487	6.2	12.35
1.05	0.612	7.0	12.9
1 11	1.198	5.8	14.6
1.13	0.650	8.7	15.2
1.33	0.950	5.6	21.6

* In the table quoted above by Lechalas from Sainjon the following note appears: "It is wrong to suppose the co-existence of rolling and suspension for the velocities 1.03 m. * * * * The absolute lack of accord with the law of advancement up to $v_1 = 1\,016$ can only correspond to a complete transformation of the method of transport. If there was a mixed period extending between the surface velocities 1 03 and 1.33, the calculated velocities would only differ gradually from the observed ones. Instead of that, we see that beyond $v_1 = 1.03$ the observed movements are not more than half the computed ones. This remaining advancement is explained by the deposit of sands held in suspension—a deposit caused by the sudden diminution of velocity below the crest. No trace of the mixed period remaining when the surface velocity reaches 1.03 m., it is probable that it was about over when the value reached 1.02 m."

The computed values of the displacement of the crest given in the last table are derived from the formula—

$$\text{Displacement} = 0.00013\ (v_1^2 - 0.11),$$

in which M. Sainjon expresses the rate of advancement of the crest so long as the surface velocity does not exceed 1.016 m. per second.

In discussing this formula M. Lechalas calls attention to the fact that this displacement becomes o for $v_1 = \sqrt{0.11}$, which virtually[1] corresponds to a bottom velocity of 0.25 m., and that one could write

$$d = m\ (v_1^2 - 0.11),$$

by giving to m the value $0.00013 \times$ the mean height of the crests in the last table corresponding to the surface velocities from 0.58 m. up to 1.016 m. This mean height is equal to 0.77 m. and the product gives $m = 0.0001$.

Whence

$$d = 0.0001\ (v_1^2 - 0.11) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (0)$$

He objects, however, to this form because v_1, the surface velocity, will vary with the depth of the stream and so introduce another variable.

Since the bottom velocity v_o ought not to vary widely, he prefers his own equation

$$d = m\ (v_o^2 - 0.06) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

to equation (0), preceding, as given by M. Sainjon.

Referring to the preceding table, he adopts the value 1.016 m. as the upper limit for surface velocities at which dragging occurs. Up to this velocity the equation (1) will be used, and beyond this limit the equation

$$d = m\ v_o^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

will be used to express the relation between solid discharge and velocity at the bottom.

It remains to find the value of v_o which corresponds to $v_1 = 1.016$ m. M. Lechalas does this by using the formulas of Darcy and Bazin

$$\frac{Z\,i}{v^2} = 0.00028 + \frac{0.00035}{Z} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (a)$$

$$\text{and } v_1 = v + 14\sqrt{Z\,i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (b)$$

By combining these two equations,

$$\frac{v_1}{v} = 1 + 14\sqrt{\frac{Z\,i}{v^2}} = 1 + 14\sqrt{0.00028 + \frac{0.00035}{Z}} \ldots\ldots (c)$$

[1] M. Sainjon (see page 369) considers $v_o = .7\,v_1$; $v_1 = \sqrt{0.11} = 0.331$; $v_o = 0.7 \times 0.331 = 0.23$ m. per second.

Substituting the value $v_1 = 1.016$ m. and the values

$$Z = \text{mean depth} = 0.5 \text{ m.}$$
$$= 1.0 \text{ m.}$$
$$= 2.0 \text{ m.}$$

he derives the corresponding values

$$v = 0.71,\ 0.75 \text{ and } 0.78.$$

By combining Darcy and Bazin's equations

$$v_1 = v + 14 \sqrt{Z\,i} \text{ and}$$
$$v_1 = v_o + 24 \sqrt{Z\,i}$$

he obtains

$$v_o = v - 10 \sqrt{Z\,i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (d)$$

which combined with (*a*) gives

$$\frac{v_o}{v} = 1 - 10 \sqrt{0.00028 + \frac{0.00035}{Z}} \quad \ldots\ldots\ldots\ldots (e)$$

Substituting the values of v which correspond to the assumed values of Z, the values of v_o are obtained—

$$v_o = 0.49,\ 0.56 \text{ and } 0.61.$$

M. Lechalas adopts a mean of these values, $v_o = 0.55$ m., as the upper limit of the bottom velocity corresponding to transport by rolling on the bed of the Loire. Since the range of velocities for which the table on page 371 gives indications of a combined mode of transport occupies such a small part of the velocity scale (from $v_1 = 1.016$ m. to $v_1 < 1.03$ m.), he assumes the same value, $v_o = 0.55$, as the lower limit of the bottom velocity corresponding to transport by suspension.

To show more clearly the actual relation of these velocity limits to the variables of the current, an ideal canal is assumed, of constant width and of a flow equal to 3 cu. m. per unit of width, so that

$$b = 1 \text{ and } q = 3.$$

Equations (*a*) and (*d*) preceding combined with the equation

$$q = Z\,v,$$

which expresses the definition of liquid discharge when b is put equal to 1, give, for $v_o = 0.55$ m.,

$$i = 0.000035,\ Z = 4.50 \text{ m., and } v = 0.67 \text{ m.}$$

and, for $v_o = 0.25$ m.,

$$i = 0.000003,\ Z = 10.00 \text{ m. and } v = 0.30 \text{ m.}$$

To express these results in the words of M. Lechalas:

"A bed of regular width, filled with sand which is not renewed, and which lies at an inclination exceeding a certain limit, receives a

discharge of 3 m. of water per second per unit of width. After a length of time greater or less, according to the fall and the length of the canal, a state of unstable equilibrium establishes itself. The mean depth is then 4.50 m., the mean velocity 0.67 m., the fall 3.5 cm. per kilometer, and the bottom velocity 0.55 m.

"The sand, however, is still transported, but in quantities smaller and smaller each second. After a considerable time a new state of equilibrium is established. This is final; it corresponds to a mean depth of 10 m., a mean velocity of 0.30 m., a fall of 3 mm. per kilometer, and a bottom velocity of 0.25 m. Although these computations apply only to an ideal channel, yet they are of interest as showing what an important role is played by the consideration of these velocity limits in the study of alluvial rivers."

Returning to the equations—

$$d = m\,(v_o^2 - 0.06) \text{ for } 0.25 \text{ m.} < v_o < 0.55 \text{ m.} \qquad (1)$$

and

$$d = m\,v_o^2 \qquad \text{for } v_o > 0.55 \text{ m.} \qquad (2)$$

M. Lechalas uses the following method to determine the value of m. By combining equations (c) and (e) of pages 22 and 23.

$$\frac{v_1}{v_o} = \frac{1 + 14\sqrt{0.00028 + \dfrac{0.00035}{Z}}}{1 - 10\sqrt{0.00028 + \dfrac{0.00035}{Z}}} \qquad (f)$$

which gives the ratio between the surface and bottom velocities in the artificial canal used by Darcy and Bazin.

The bottom velocity ought to be less dependent upon the depth than that at the surface. If a formula is expressed in terms of the bottom velocity, it may properly be transformed into terms of the surface velocity and mean depth, or of mean velocity and mean depth. On the other hand, when the formula is in terms of the surface velocity, and it is desired to express it in terms of the bottom velocity, it is necessary to assume the ratio $\frac{v_1}{v_o}$ a constant for all values of the mean depth. This introduces an approximation unavoidable without a new series of observations.

Assuming $Z = 1$ meter[1] in equation (f)

$$\frac{v_1}{v_o} = 1.80.*$$

[1] The mean of the values of Z used to obtain the critical value $v_o = 0.55$ m., and hence the most consistent value to use in determining m.

* For $Z = 3$ m., $\frac{v_1}{v} = 1.60$.

Equation (0) page 372, which is based upon M. Sainjon's empirical formula, may be considered reasonably accurate for the range of velocities for which it is intended, as can be seen from a study of the computed results in the table of page 371.

Equation (0) and equation (1) of page 372 may now be written

$$d = 0.0001\ (v_1^2 - 0.11) = m\ (v_o^2 - 0.06)$$

and, by introducing the approximate value $v_1 = 1.80\ v_o$ from page 374, the value found

$$m = \frac{0.0001\left(\overline{1.8\,v_o}^{\,2} - 0.11\right)}{v_o^2 - 0.06}$$

For $v_o = 0.50$ m. per second.

$$m = 0.00037[1]$$

and M. Lechalas' equation (1) becomes

$$d = 0.00037\ (v_o^2 - 0.06) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

and (2) becomes

$$d = 0.00037\ v_o^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The objections to the introduction of the uncertain value of the ratio $\frac{v_1}{v_o}$ in obtaining these final equations are all admitted, but M. Lechalas maintains that if a numerical coefficient can be used when the discharge d is expressed in terms of v_1 at the surface,[2] one can be much more reasonably used when the equation is in terms of the bottom velocity v_o.

The years 1874 to 1879 marked the arousal of a great popular interest in the United States in the question of silt movements in the Mississippi. The bitter controversy between the Government engineers and Captain James B. Eads with his associates over the improvement of the mouth of the river need not be entered into here. Suffice it to say that the many spirited articles written on the subject during those years were not of great scientific value and left the knowledge of the distribution of the sediment in the river in the same state of incompleteness in which it was left by the report of Humphreys and Abbot in 1861.

Mr. Eads states his views in a letter[3] of March 15, 1874, with reference to these sediment movements in the following words:

[1] For values of v_o between 0.40 m. and 0.55 m., the corresponding values of m range between 0.00041 and 0.00036.

[2] As is done in the equation (0) based on M. Sainjon's formula; displacement = 0.00013 × (v_1^2 — 0.11).

[3] To William Windom, United States Senate, Chairman of Committee on Transportation Routes to the Seaboard.

See "The Mississippi Jetties," p. 28, E. L. Corthell, New York, 1881.

"By far the greatest portion is, however, transported in suspension. The amount of this matter and the size and weight of the particles which the stream is enabled to hold up and carry forward depend wholly upon the rapidity of the stream, modified, however, by its depth. * * * A certain velocity gives to the stream the ability of holding in suspense a proportionate quantity of solid matter and when it is thus charged it can sustain no more. * * * The fact that a given current will keep in suspension a corresponding quantity of solid matter; that at a less velocity a portion of it will be deposited and taken up again at a greater, is fully recognized in experimental science and has been extensively made use of for analysis of soils. An eminent investigator of this subject, Prof. E. W. Hilgard, of the University of Michigan, now of the University of California, Oakland, Cal., has classified silts according to the different velocities at which they deposit.[1] This independent line of research fully confirms the view herein advanced in explanation of the phenomena presented through the alluvial bed of the Mississippi."

Gen. A. A. Humphreys, Chief of Engineers, expresses his views in a report[2] to the Secretary of War, dated April 15, 1874, in the following words:

"It has been recently stated by a civil engineer,[3] in a pamphlet concerning the improvement of the mouths of the Mississippi River by jetties, that the amount of sedimentary matter carried in suspension by the Mississippi River is in exact proportion to the velocity of its current; and that, as a given velocity of current will keep in suspension a corresponding quantity of solid matter at a less velocity a certain portion of it will be dropped. * * * The first statement is in direct conflict with the results of the long-continued measurements made upon the quantity of earthy matter held in suspension by the Mississippi River at Carrollton, near New Orleans, and at Columbus, 20 miles below the mouth of the Ohio, one of the chief objects of which was to determine this very question, whether any relation existed between the velocity and the quantity of earthy matter held in suspension. These results prove that the greatest velocity does not correspond to the greatest quantity of earthy matter

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[1] *American Journal of Science* III, VI, 337.

"The classified table of Prof. Hilgard gives the relative velocities created in a mechanical contrivance made for test purposes in a laboratory in which coarse sand is dropped at a certain velocity of the machine, which may be represented in nature as a current of about 2.5 ins. per second; the finest sand when the current is 0.3 of an inch per second; the coarsest silt when the velocity is 0.14 of an inch per second; the finest silt when the velocity is 0.02 of an inch per second."

"Report of Chief of Engineers, U. S. Army," 1874, Part I, p. 865.

[2] "Report of Chief of Engineers, U. S. Army," 1874. Part I, p. 863.

[3] James B. Eads.

held in suspension; on the contrary, at the time of the greatest velocity of the current at Carrollton, the river held in suspension but little more sediment per cubic foot than when the velocity was least. When the quantity of earthy matter held in suspension was greatest the velocity was 2 ft. per second less than the greatest velocity, the quantity of earthy matter in the one case being three times as great as in the other. We find at another time, when the velocity was one-half the greatest velocity the quantity of earthy matter held in suspension was double the amount. Again, we find the quantity of earthy matter in suspension the same, the velocity in the one case being 6.75 ft. per second, and in the other, 1.5 ft. per second.

I.—Carrollton, 1851.

Date.	Weight in grains of sediment in 1 cu. ft. of water.	Mean velocity of river in feet, per second.	Remarks.
February 20th	450	6.5	
March 20th	200	6.2	
April 15th	150	5.6	
May (last week of)	100	3.75	
June 20th	650	4.3	
July 10th to 30th	450	4.8	
August 1st to 20th	450	From 4.8 to 3.5	Change in velocity regularly decreasing, while suspended matter remains the same.
September 8th	300	3.0	
October and November	100	1.75	
December	175	1.85	
January 20th, 1852	400	2.75	

II.—Columbus. Twenty Miles below the Mouth of the Ohio, 1858.

Date.	Weight in grains of sediment in 1 cu. ft. of water.	Mean velocity of river in feet per second.	Remarks.
April 1st	300	7.00	
April 10th	300	5.25	
April 25th	450	7.25	
May 1st	300	7.50	
May 10th	300	5.75	
May 22d	160	6.75	
June 16th	330	8.25	
July 16th–17th	650	3.75	
August 2d	350	4.75	
August 9th	250	4.00	
September 2d	600	2.50	
September 9th to 23d	200	2.25	
October (all of)	200 to 100	1.50	Uniform decrease in amount of sediment, the velocity remaining the same.

"The tables (on page 377) illustrating what has just been said, have been prepared from the report on the Mississippi River. The figures given express the conditions not only on the day noted, but on several successive days.

"It is to be remarked that the investigations respecting the sediment in suspension show that the quantity depended on the river from which the volume of discharge was at the time chiefly derived.

"The cross-sections, both at Carrollton and Columbus, remained unchanged during the above observations."

In order to define still more clearly the position of General Humphreys on this question, the following quotation is made from his report of 1875:[1]

"It has been sometimes stated that every velocity of current is capable of carrying in suspension a certain fixed quantity of earthy matter, and that the water of a muddy river is always thus charged with the maximum quantity of earthy matter it can carry. * * * But this assumption as to the carrying power of currents is utterly disproved by long series of exact measurements upon the Mississippi River. * * * These measurements upon the quantity of earthy matter suspended in the Mississippi River show that at no time has the water been so heavily charged with it that the current could not carry it along in suspension to the same extent as it did when the quantity of earthy matter was least; and they further show that the current of the Mississippi River, when most feeble, can carry in suspension the greatest quantity of suspended earthy matter found in it to the same extent that it can carry the least quantity found in it.

"It was undoubtedly the observation of facts similar to these that led to the conclusion, entertained by some, that the suspending power of the current of a river did not depend upon its absolute rate of motion, but upon the difference of velocity between the adjoining fillets of water. There is good reason to conclude that this is one of the causes or sources of the suspending power of a stream.

"This proposition, therefore, respecting certain velocities of current always carrying certain fixed quantities of earthy matter, and always adjusting those quantities according to its own variations of strength is so entirely disproved by facts that it will not be considered again."[2]

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[1] Annual Report of Chief of Engineers, U. S. A.," 1875, Part I., pp. 959-975. Reprinted in Humphreys and Abbot's "Report on the Mississippi River." Edition of 1876. Appendix M, p. 684.

[2] Those readers who wish to go farther into the details of this somewhat amusing controversy are referred to Humphreys and Abbot's Report on the Mississippi River, Edition of 1876. Appendices.

Review of same by James B. Eads, M. Am. Soc. C. E., in *Van Nostrand's Engineering Magazine*, Vol. XIX, 1878, pp. 211-229.

Answer to Mr. Eads' attack by General Henry L. Abbot, *Van Nostrand's Engineering Magazine*, January, 1879, Vol. XX, pp. 1 6.

Answer to General Abbot by Mr. Eads, *Van Nostrand's Engineering Magazine*, Vol. XXI, 1879, p. 154.

An article by Mr. G. K. Gilbert,[1] upon the erosion of the Colorado cañons, appeared in the *American Journal of Science*, July and August, 1876. While subject to some criticism, it may be regarded as a most valuable contribution to the knowledge of the laws of transport of solid bodies by water currents. It is believed that Mr. Gilbert is the only writer who has called attention to the fact that the same expenditure of energy will transport a greater weight of fine particles than of coarse ones of the same density.

A series of observations was conducted by Assistant Engineer J. B. Johnson at Helena, on the Mississippi River, in 1879.[2] Longitudinal and transverse soundings were made to determine the existence and movement of sand waves in the river bed, and the results plotted[3] so as to show clearly the presence of these undulations. From the observations Mr. Johnson deduces the following facts:

"Average length of waves from crest to crest, about 100 m.

"Extreme length of waves from crest to crest, about 150 m.

"Average height of waves from crest to valley, about 5 ft.

"Extreme height of waves from crest to valley, about 8 ft.

"Average velocity of motion of crest, 5.41 m. per day.

"These results were obtained in a depth of water varying from 13 to 30 ft. The stage of the river varied from 12 to 18 ft. above low water at Helena. The waves decreased in size for a falling river and *vice versa*. Their rate of motion down stream is a function of the velocity of the water. They do not extend from bank to bank at Helena but disappear about 200 m. from each shore, covering about 1 000 m. of the cross-section of the river."

Sediment measurements were made by the same party from March 1st to June 18th, 1879, and deserve special mention because of the introduction of an improved sediment can[4] for bringing up specimens from the bottom.

Samples were taken each day from the surface and 1 ft. above the bottom at points one-fourth and three-fourths of the distance across the river. Proportions of sediment were determined by weight in the later experiments and the mean velocity of the river was determined by floats upon five occasions during the extent of the observations.[5]

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[1] See digest in *Engineering News*, August 19th, 1876.

[2] See "Report of Chief of Engineers, United States Army," 1879, Part III, pp. 1963-1970.

[3] See Plate I, p. 1966. "Report of Chief of Engineers," 1879, Part III.

[4] For sketch, see "Report of Chief of Engineers, United States Army," 1879, Part III, p. 1965.

[5] The tabular result of these observations is given at p. 1969 of above Report.

Simultaneous observations of a like nature were conducted at St. Louis[1] by R. E. McMath. They are more satisfactory in that they offer a slight opportunity for study of transverse distribution of sediment. Both sets give velocity measurements.

The most extended set of observations published upon sediment movements and sand waves are those instituted by the Mississippi[2] and Missouri[3] Commissions in 1879–1881. These were made at St. Louis, Carrollton, Prescott, Winona, Clayton, Hannibal, Grafton and St. Charles. They are wide enough to put at rest certain debated questions, but yet fail in several points to be completely satisfactory—notably in failing to give data on horizontal distribution. These measurements will be again referred to.

Major Allan Cunningham made a series of observations on the Ganges Canal[4] to determine the amount of sediment carried and its distribution in the cross-section.

A tube 12 ft. long, open at both ends, was thrust down vertically from a floating boat until the bottom was reached. It was then closed at the bottom, by a lid worked by a spring, and the column of water, extending from bed to surface, carefully separated from its sediment by decantation and filtration.

This sediment, when weighed, gave a result, called silt-density, which represented the average density in the vertical examined.

To determine the distribution of silt, two collections were made, by the method indicated, at each of nine points in the width of the canal at two different cross-sections. Each set was completed as rapidly as possible. The mean silt velocity past each vertical was computed by multiplying this silt density by the corresponding mean velocity. Captain Cunningham then plotted three transverse curves on a common base, using as ordinates the silt density, the mean silt velocity, and the mean velocity past each of the nine verticals. From the want of relative connection between these curves he concludes that in the Ganges Canal there is no close relation between the silt and the velocity at different parts of the channel, and that the silt density at any point varies from instant to instant.

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1 *Van Nostrand's Engineering Magazine*, 1883, p. 33.

2 "Report of Chief of Engineers United States Army," 1883, III.

3 "Report of Chief of Engineers, United States Army," 1887, IV.

4 "Roorkee Hydraulic Experiments," Roorkee, 1881, Chap. XXIV. Abstracted and discussed in *Proceedings* of the Institute of Civil Engineers, 1882, Vol. LXXI, pp. 1–94. Same reproduced in *Van Nostrand's Engineering Magazine*, April and May, 1883.

In continuation of these measurements, 73 collections were made at four of the cross-sections, the depth and velocity at two of them being very different. These results led to the conclusion that the mean silt density in no way depended upon the depth or velocity in this canal, but rather upon the state of the supply water from the Ganges.

The best known formula for the determination of the size of particles dragged by a current of a given velocity is that proposed by Mr. Wilfred Airy, and derived by him as follows:[1]

Let $a =$ the length of the largest cube the current could move.

Then weight of cube $= \gamma' a^3$ (γ' const.).

Friction of cube on bed of river $= f' \gamma' a^3$ (p const.).

Total pressure of current on exposed face of cube $= k\ a^2\ v_o^2$ (k const.)

For equilibrium—

$$f' \gamma' a^3 = k\ v_o^2\ a^2$$

whence

$$a = \frac{k}{f' \gamma'} v_o^2$$

therefore the weight of the largest cube which a current with a bottom velocity v_o could move would be

$$\gamma' a^3 = \gamma' \left(\frac{k}{f' \gamma'} v_o^2 \right)^3 = \frac{k}{f'^3 \gamma'^2} v_o^6$$

If G' and G'' were the weights of cubes of silt, etc., which could just be moved by currents of bottom velocities v_o' and v_o'' respectively, then

$$\frac{G'}{G''} = \left(\frac{v_o'}{v_o''} \right)^6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

or, numerically:

If v_o is increased by $\frac{1}{8}$ of itself, it will move particles of twice the weight, since $\left(\frac{1}{1\frac{1}{8}} \right)^6 = \frac{1}{2}$; and if the velocity v_o is doubled, it will move particles of 64 times the weight, since $\left(\frac{1}{2} \right)^6 = \frac{1}{64}$.

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[1] See condensed description in *Proceedings* of the Institution of Civil Engineers, Vol. 82, p. 25. Notation changed.

See Church's "Mechanics of Engineering," p. 831.

A formula, showing that the scouring power of a natural stream is proportional to the seventh power of the velocity, is said to have been proposed about 1855, by W. Hopkins, of Cambridge, England.

See Baldwin Latham in *Proceedings* of the Institution of Civil Engineers, Vol. 82, p. 43.

Mr. Henry Law shows this formula to be also applicable to the case of a cube rolled along instead of sliding, and to be true for a sphere as well as a cube.[1] His proof follows:

The moment of resistance of the cube to turning about its edge is

$$\gamma' a^3 . = \frac{a}{2} = \gamma' \frac{a^4}{2}$$

The turning moment of the thrust of the current is

$$k\, a^2\, v_o^{\,2} \;.\; \frac{a}{2} = \frac{k\, a^3\, v_o^{\,2}}{2}$$

At the instant of turning the equation of equilibrium gives

$$\gamma' \frac{a^4}{2} = \frac{k\, a^3\, v_o^{\,2}}{2}$$

whence

$$a = \frac{k}{\gamma'} v_o^{\,2}$$

Following the same process used by Airy above, this leads to his formula (1).

In the case of spheres, assume each one to be resting upon three others.

Weight of sphere $= \frac{4}{3} \pi r^3 \gamma'$.

Let r sin. $\beta =$ lever arm of weight about point of turning.

Then moment of resistance to turning is

$$\frac{4}{3} \pi r^3 \gamma' . r \sin. \beta = \frac{4}{3} \pi \gamma' r^4 \sin. \beta$$

Thrust of the current $= k \pi r^2 v_o^2$.

Its lever arm about the point of turning would be r cos. β.

Then the turning moment due to the thrust would be

$$k \pi r^3 v_o^{\,2} \cos. \beta.$$

For impending motion, the equation of equilibrium gives

$$k \pi r^3 v_o^{\,2} \cos. \beta = \frac{4}{3} \pi \gamma' r^4 \sin. \beta$$

whence

$$r = \frac{3}{4} \frac{k}{\gamma'} v_o^{\,2} \cot. \beta.*$$

This again leads to Mr. Airy's equation (1) as above, β being constant as r varies.

[1] See *Proceedings* of the Institution of Civil Engineers, Vol. 82, pp. 29-30. Notation changed.

* Through an oversight, Mr. Shaw has obtained an incorrect numerical coefficient for this last equation in having used, for the value of the section of the sphere normal to the current, $\frac{1}{2} \pi d^2$ instead of $\frac{1}{4} \pi d^2$. It is corrected here.

Mr. Shaw then concludes that the weight of particles moved by a current, whether cubes or spheres, and whether the action be sliding or rolling, will vary as the sixth power of the mean velocity of the current impinging on them, if cohesion between the particles be disregarded.

M. J. Thoulet, Professor of Science, at Nancy, published in 1884 the results[1] of some experiments made to determine the force required to keep particles of different sizes and densities suspended in water.

The apparatus used consisted of a glass tube placed in a vertical position and connected at its lower end by a rubber tube with a stopcock to regulate the velocity of a water-current ascending through the glass tube. The water was led away by a waste-pipe connected near the top, and the velocity for each experiment determined from the weight of water flowing. The details of the experiments were carried out with scientific exactitude.[2]

M. Thoulet computed the mean velocity of the current required in tubes of four different diameters (2.2, 4.775, 6.75 and 8.0 mm.) to hold unmoved, at a fixed point, spheres of different sizes and densities. These spheres were lead bullets of different calibers and balls of wax containing, in their interior, grains of tin, lead or copper. Their sphericity was tested under the microscope, and in all cases they were kept at the specified height for a length of time not less than 30 seconds.

From his results M. Thoulet has computed a table giving in millimeters per second the velocities of vertical currents of water capable of holding in suspension, at a fixed height in the tube, spherical grains of known radii and of given densities. These radii vary from 1 to 2.5 mm. and the densities from 1.5 to 4. The table[3] also gives, in milligrams, the thrust of the current against the grain.

This thrust is equal to the resultant weight of the grain immersed in water, *i. e.*,

$$\tfrac{4}{3}\,\pi\,r^3\,(\gamma' - 1) = \text{thrust}$$

and M. Thoulet has computed the values corresponding to the different values of r and γ' from this formula.

Making the assumption of spherical grains in a stream bed, he considers that each one may be regarded as resting on three others, and

[1] *Annales des Mines*, 1884, I, pp. 507–530. For digest, see *Annales des Ponts et Chaussées*, 1885, I, pp 492–500.

[2] See description in *Annales des Mines*, 1884, I, pp. 507–530.

[3] The same, p. 521. See p. 76 of this paper.

shows graphically that for a horizontal movement a force will be required sufficient to move the grain up a slope of about 37°.[1]

This force $= \frac{4}{3} \pi r^3 (\gamma' - 1)$ sin. 37°.

By referring to his table M. Thoulet determines the bottom velocities required to exert a force equal to that demanded by this formula for the three cases given below.

Material.	Diameter of grains in millimeters.	Velocity required in millimeters per second.
Coarse mud	0.40	40.00
Fine sand	0.70	59.68
River sand	1.70	109.58

M. Vauthier, in a valuable paper[2] before the French Association for the Advancement of Science, in 1884, developed mathematical expressions for the velocity, at any instant, of a solid body falling through a liquid, and for the path described in a given time.

His method consists in writing the accelerating force equal to the mass multiplied by the acceleration of the body, assumed to be a sphere.

Accelerating force = weight of body — resisting force

$$= \frac{4}{3} \pi r^3 (\gamma' - 1) - \pi r^2 k \frac{v^2}{2g}$$

When the motion has become uniform the accelerating force will be zero, and one may write for this case.

$$\frac{4}{3} \pi r^3 (\gamma' - 1) - \pi r^2 k \frac{v'^2}{2g} = 0 \quad \ldots\ldots\ldots\ldots \quad (1)$$

whence,

$$v' = 2 \sqrt{\frac{2}{3} \frac{r\,g}{k} (\gamma' - 1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where v' represents the limiting velocity, after which motion is uniform.

For any stage of the motion

$$\frac{4}{3} \pi r^3 (\gamma' - 1) - \pi r^2 k \frac{v^2}{2g} = \frac{4}{3} \frac{\pi r^3}{g} \gamma' \frac{dv}{dt} \quad \ldots\ldots \quad (3)$$

$$= \text{mass} \times \text{acceleration.}$$

[1] This is the value of the angle β in Mr. Shaw's analysis preceding.

[2] "De l'entrainement et du transport, par les eaux courantes, des vases, sables et graviers."

L. L. Vauthier, "Mémoires de l' association française pour l' avancement des sciences," Blois, September 8, 1884.

Abstracted at length in the "Mémoires de la Société des Ingénieurs Civils de France," 1885, 2, pp. 29-35.

General results also given in *Engineering News*, November 1, 1884, p. 211.

Subtracting (1) from (3) and simplifying

$$k\,(v'^2 - v^2) = \frac{8}{3}\, r\, \gamma'\, \frac{d\,v}{d\,t}.$$

Separating the two variables

$$\frac{3}{8}\,\frac{k}{r\,\gamma'}\,d\,t = \frac{d\,v}{v'^2 - v^2} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (4)$$

Since $v = o$ for $t = o$ one may write:

$$\int_o^t \frac{3}{8}\,\frac{k}{r\,\gamma'}\,d\,t = \int_o^v \frac{d\,v}{v'^2 - v^2}$$

Integrating by partial fractions

$$\frac{3}{8}\,\frac{k}{r\,\gamma'}\,t = \frac{1}{2\,v'}\left(\int_o^v \frac{d\,v}{v' + v} - \int_o^v \frac{-\,d\,v}{v' - v}\right)$$

$$= \frac{1}{2\,v'}\,\log._e \left(\frac{v' + v}{v' - v}\right)$$

whence,

$$e^{\frac{3}{4}\,\frac{k}{r\,\gamma'}\,v'\,t} = \frac{v' + v}{v' - v}.$$

Putting

$$N = \frac{3}{4}\,\frac{k}{r\,\gamma'}\,v' \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (5)$$

and transforming

$$v = v'\,\frac{e^{Nt} - 1}{e^{Nt} + 1} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (6)$$

and, since $d\,s = v\,d\,t$

$$d\,s = v'\,\frac{e^{Nt} - 1}{e^{Nt} + 1}\,d\,t \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (7)$$

whence, by integration, since when $s = o$, $t = o$:

$$s = v'\left[t - \frac{2}{N}\log._e 2 + \frac{2}{N}\log._e\left(1 + \frac{1}{e^{Nt}}\right)\right] \text{[1]} \quad \cdots\cdots \quad (8)$$

---

[1] Put $e^{Nt} - 1 = u$ and $e^{Nt} + 1 = u + 2$.

Then $e^{Nt} = u + 1$. Differentiating, $du = e^{Nt}\,N dt$,

or
$$dt = \frac{du}{N\,e^{Nt}} = \frac{1}{N}\,\frac{du}{u+1}.$$

Substituting these values in (7) above

$$ds = v^1\,\frac{u}{u+2}\,\frac{1}{N}\,\frac{du}{u+1} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (a)$$

Separating into partial fractions by the method of indeterminate coefficients (cf. Osborne's "Differential and Integral Calculus," p. 189).

$$\frac{u}{(u+1)\,(u+2)} = \frac{2}{u+2} - \frac{1}{u+1}$$

Substituting this value in (a) and integrating

$$\frac{N}{v^1}\,s = 2\int\frac{du}{u+2} - \int\frac{du}{u+1} + C, \text{ or}$$

$$\frac{N}{v^1}\,s = 2\log._e\,(u+2) - \log._e\,(u+1) + C \quad \cdots\cdots\cdots\cdots\cdots \quad (b)$$

(Footnote continued on next page.)

Assuming $k = 0.5$ and $\gamma' = 2.0$ for a mean of the particles moved in river beds, and $g = 9.8088 = 10$, approximately, M. Vauthier obtains from (2) and (5) (for meter measure).

$$v' = 5.16393 \sqrt{2r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

$$N = \frac{1.93648}{\sqrt{2r}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

This last equation shows that for particles of slight diameter, the value of N, and consequently of e^N, is very large.

Writing equation (6) in the form

$$v = v' \frac{1 - \frac{1}{e^{Nt}}}{1 + \frac{1}{e^{Nt}}}$$

it is at once seen that the fraction in the second member rapidly approaches the value 1 as the diameter of the particle is decreased, *i. e.*, as N approaches ∞. Therefore v approaches v' asymptotically, and at the limit the two will be equal.

For the same reason given above the transcendental term in equation (8) will be so small as to be negligible for particles of slight diameter.

By numerical substitution in equations (9), (10), and (8). M. Vauthier shows that, for a block as large as 1 m. in diameter, at the end of the first second the velocity will be only about ¾ of the velocity limit v', and the transcendental term in (8) will be too large to be neglected, but that, with succeeding seconds, it tends rapidly to approach the value v', while the transcendental term tends rapidly toward o.

When $s = o$, $t = o$, and hence $u = o$, since $u = e^{Nt} - 1$. Substituting these values in (*b*) and solving for C

$$C = -2 \log._e 2.$$

Substituting this value in (*b*) and introducing the values of $(u + 1)$ and $(u + 2)$

$$s = \frac{2\, v^1}{N} \log._e (e^{Nt} + 1) - \frac{v^1}{N} \log._e e^{Nt} - \frac{v^1}{N} 2 \log._e 2 \quad \ldots\ldots\ldots \quad (c)$$

To the second number of (*c*) adding and subtracting $\frac{2\, v^1}{N} \log._e e^{Nt}$,

and collecting similar terms

$$s = v^1 \left[\frac{2}{N} (\log._e (e^{Nt} + 1) - \log._e e^{Nt}) + \left(\frac{2}{N} - \frac{1}{N} \right) \log._e e^{Nt} - \frac{2}{N} \log._e 2 \right]$$

Since $\log._e e^{Nt} = Nt$, and

$$\log._e (e^{Nt} + 1) - \log._e e^{Nt} = \log._e \frac{e^{Nt} + 1}{e^{Nt}} = \log._e \left(1 + \frac{1}{e^{Nt}} \right)$$

there results finally

$$s = v^1 \left[t - \frac{2}{N} \log._e 2 + \frac{2}{N} \log._e \left(1 + \frac{1}{e^{Nt}} \right) \right]$$

Compare Rühlmann's "Hydromechanik," p. 699, for a similar solution.

To determine the length of the period of time required before the velocity of particles of different sizes becomes practically uniform, M. Vauthier has expanded equation (6) by division into

$$v = v' \left[1 - \frac{2}{e^{Nt}} + \frac{2}{e^{2Nt}} - \frac{2}{e^{3Nt}} + \ldots\ldots\ldots\ldots \right]$$

For all but very large bodies all but the first two terms may be neglected. To find the length of time before the actual velocity will differ from the velocity limit by $\frac{1}{1000}$, one may put

$$\frac{2}{e^{Nt}} = \frac{1}{1000},$$

where $e^{Nt} = 2\,000$, and

$$t = \frac{\log.\ 2\,000}{N \log.\ e} \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

From equations (5) and (11) M. Vauthier has prepared a table for particles of different diameters, showing the length of the path described in the first four seconds, and the length of time elapsing before the actual velocity lacks only $\frac{1}{1000}$ of the velocity limit v'.

This table shows how rapidly the velocity of fall approaches the velocity limit in each case, especially with the smaller particles. It is not until the diameter of the particle becomes as great as 1 m. that there is an appreciable difference between the two at the end of the third second, and even then the difference is slight.

Assuming a particle free to descend with a vertical velocity v in a current of water whose mean horizontal velocity is u, its vertical velocity, except in the case of very large bodies, may be put equal to the corresponding velocity limit v'.

The direction of its path, while not a straight line because of the relative velocities of the filaments of water, will yet, in general, form an angle with the horizon whose tangent is $\frac{v'}{u}$.

If the height above the bottom at starting was z it will reach the bed of the stream after a time

$$t = \frac{z}{v'}$$

and at a distance down stream

$$l = z\frac{v'}{u}.$$

With numerical values M. Vauthier obtains the following results:

Diameter of particle $2r$ (in meters).	Velocity of current u (in meters).	Original height above bed z (in meters).	Time in sinking to bottom t (in seconds).	Distance traversed down stream l (in meters).
0.0001 (mud)	1.00	1.00	19.38	19.38
0.001 (sand)	1.00	1.00	6.12	6.12
0.01 (gravel)	1.00	1.00	1.94	1.94

Suppose this body, falling through the water with a vertical velocity v', meets an upward accidental current with a vertical component equal to v'. It would be kept in suspension so long as the current endured. This is held by M. Vauthier to explain the phenomenon of suspension.

He draws the following conclusions from his study:

"(*a.*) Water does not possess a special property by virtue of which it holds in suspension minute particles of a density superior to its own.

"(*b.*) These particles always move toward the bottom with a velocity which depends upon their density and which is inversely as the square root of their transversal dimensions.

"(*c.*) From the value of these velocities, for materials of a density similar to those which form the surfaces of the beds of water courses, the effects of displacement and of transport observed in streams and rivers is very well explained by the single fact of accidental or permanent currents which act upon the bottom."

In his "Hydraulique"[1] M. Flamant has brought together the most valuable parts of the theories advanced by Dupuit, Vauthier, Partiot, Sainjon and Lechalas. His work is of especial interest in that he calls attention to the bearing upon this question of an article by M. Du Boys[2] intended to complete Dupuit's explanation of the increased velocity of a surface float over that of the mean of the surrounding filaments of water. M. Du Boys has completed the explanation of Dupuit by adding that, while the displaced water and the floating body are alike subjected to the accelerating force due to gravity, yet the resistances to which they are subjected are different. In the displaced water, a portion of the gravity work is lost from the non-parallelism of the filaments and the consequent internal frictions, while in the floating body all the accelerating force due to gravity is used in overcoming the friction on the sides and in producing the increased velocity.

[1] "Mécanique Appliquée, Hydraulique" pp. 290–311. M. A. Flamant, Paris, 1891. Baudry & Cie.

[2] *Annales des Ponts et Chaussées*, 1886, I, p. 199.

In summing up the results of his study, M. Flamant expresses the belief that the power of suspension increases with the quantity $\frac{d\,v}{d\,z}$, with the mean or bottom velocity and with the depth.

Experiments reported by Mr. G. F. Deacon in connection with studies for the Manchester Ship Canal give an accurate description of the detailed action of flowing water upon a bed of sand. His summary of results[1] will be reproduced here.

"The observations were made in a long flat-bottomed trough with glass sides by means of which the behavior of the sand could be accurately observed. The sand was from the estuary of the Mersey, the quantities moved were weighed and the surface velocities of the water carefully measured. When water flowed with a steadily increasing velocity over a surface of such sand, fine pieces of broken shell were first moved, and the surface velocity required to produce such movements was considerably less than 1 ft. per second. At such velocities, however, the sand proper was perfectly stable, and however long the flow continued it remained undisturbed; but the fine pieces of shells at the surface of the sand moved in spasmodic leaps, accumulating wherever the velocity was somewhat less.

"The first movement of sand began at a surface velocity of 1.3 ft. per second. This movement was confined to the smaller isolated grains; and if the same velocity was maintained, the grains so moved ranged themselves in parallel bands perpendicular to the direction of the current, each band taking the form of the well-known sand ripples of the sea shore or sand-bottomed stream, with its flat slope upwards and its steep slope downwards in the direction of the current. At this velocity the profile of each sand ripple had a very slow motion of translation, caused by particles running up the flatter slope and toppling over the crest. The steep downward slope was, therefore, being constantly advanced at the expense of the denudation of the less steep upward slope. At a surface velocity of 1.5 ft. per second the sand ripples were very perfect and traveled with the stream at a speed of about $\frac{1}{2160}$ of the surface velocity. At a surface velocity of 1.75, the ratio was reduced to about $\frac{1}{1050}$, and at a surface velocity of 2 ft. to $\frac{1}{480}$. A critical velocity was reached when the surface of the water moved at 2.125 ft. per second, when the sand ripples became very irregular. indicating greatly increased unsteadiness of motion of the water. Up to this point the whole amount of scour was represented by the volume of the sand waves multiplied by an exceedingly low velocity, always less than the $\frac{1}{480}$ part of the surface velocity of the water. At about this critical velocity of 2.1 ft. per second, the particles rolled by the water up the flat slope, instead of toppling over the steep

[1] *Proceedings* of the Institution of Civil Engineers, 1894, Vol. 118, pp. 93–95.

slope, were occasionally carried by the water direct to the next crest; and as the velocity of the water was gradually increased, an increasing bombardment of each crest by the crest behind it took place.

"At about 2.5 ft. per second, another critical velocity was reached and many of the little projectiles cleared the top of the first or even of the second crest ahead of that from which they were fired. At surface velocities of 2.6 to 2.8 ft. per second, the sand ripples became more and more ghost-like, until, at 2.9 ft. per second, they were wholly merged in particles of sand rushing along with the water in suspension. After this the scour was of a totally different character; the sand and water became mixed, and a constant process of lifting, carrying and depositing of individual particles ensued, the sand being stirred to a depth and lifted to a height dependent upon the velocity."

Mr. Deacon refers to the theory that the weight of sand moved is proportional to the sixth power of the velocity of the water and believes the method of determination of this law to be fallacious. His observations showed that, within the limits of the experiments, the weight of material transported was proportional to the fifth power of the surface velocity or possibly a little more. Two curves are given expressing the results. One shows the relation between the surface velocity and the solid discharge in pounds of sand; the other, the ratio between the surface velocity of the current and the velocity of translation of the crests of the sand ripples.

M. Gallois has described[1] a method of experiment,[2] which throws light upon the problem of suspension. A glass bottle 3 ins. in diameter is used and its flat bottom covered to a depth of 0.2 in. with clean sand. By corking so as to exclude all air and rotating rapidly by means of a twisted cord or a turn-table, the sand is thrown by centrifugal force against the sides of the bottle. The motion of the bottle is communicated to the water progressively from the sides to the center, the sand remaining at the outside. If the bottle be suddenly stopped when the velocity of the water has come to equal its own, the sand will at once project itself from the sides to the center in a cloud, gradually subsiding to form a cone at the bottom, with a vertical axis, whose length increases with the velocity of rotation.

This cone flattens with decrease in velocity, until in still water it assumes the corresponding slope of equilibrium for sand. M. Gallois

[1] *Le Genie Civil.* See *Engineering News*, March 23, 1893, for a brief digest.

[2] Suggested by Dupuit in 1848. See page 360, and also "Etudes sur le Mouvement des Eaux," Dupuit, pp. 216-217; Flamant "Hydraulique," 1891, p. 302. Footnote.

explains this phenomenon as follows: When the rotation of the bottle is stopped, the water continues to revolve, but is gradually brought to rest by the friction from the sides of the bottle. Since this retarding force communicates its action progressively from the outside inward, the interior filaments soon attain a relative velocity with reference to the outer ones which increases toward the axis of rotation. The sand is pushed toward the center with a force which is proportional to the velocity of the fluid. Consequently the cone flattens as the velocity of rotation decreases.

M. Fargue has recently described[1] some experiments of a similar nature started by him in 1872 and repeated lately at Rouen and Langon. The apparatus used consisted of a circular disc upon which a zinc annular ring, about 0.30 m. high, was fixed. The internal and external radii were respectively 0.50 m. and 1.0 m. The disc was so mounted upon a vertical axis as to be given any desired rate of rotation.

By partly filling the ring with water and carefully increasing the rate of rotation a paraboloid of revolution was soon formed by the water surface.

If a uniform bed of sand and gravel was placed on the bottom before rotation began, and a number of floats at the surface, certain phenomena were seen to occur.

Up to a velocity of 1 rotation in 4 seconds the solids remained unmoved on the bottom. When the time of revolution had decreased to 3.5 seconds, isolated grains of sand and gravel moved to the concave side. This radial movement increased with the speed until, at a velocity of 1 turn in 2½ seconds, the entire mass of gravel was collected on the concave side and showed a somewhat regular surface. The floats, on the other hand, gradually descended the surface of the paraboloid until certain ones became stranded on the convex side or the bottom.

After the conditions had become fixed, the disc was suddenly stopped. The water continued its motion in a state of agitation corresponding to the angular velocity at the moment of arrest. The hollow formed toward the axis was at once filled and the surface became horizontal. The gravel was carried toward the center, with a rapidity corresponding to the angular velocity at which the disc was stopped.

[1] "Expériences relatives à l'Action de l'Eau Courante sur un Fond de Sable." Paris. M. Fargue, Inspecteur-Général des Ponts et Chaussées, *Annales des Ponts et Chaussées*, March, 1894.

When this velocity was 0.74 (time of rotation, 8.5 seconds), the materials covered the bottom almost uniformly. The disc was only bare for a discontinuous strip at the outer edge. When the velocity of stoppage was 1.11 (time of rotation, $5\frac{2}{3}$ seconds), the sand and fine gravel moved rapidly to the convex wall and the average gravel spread itself almost uniformly, except that only a few of the large particles remained at the concave wall. When it was 3.14 (time, 2 seconds), all the gravel was violently thrown toward the center and the fine sands followed in spirals of varying lengths. There was little regularity in the motion of the floats, though they generally kept to the concave bank.

PART II.—DISCUSSION OF OBSERVED DATA.

The extent of the erosive action of water courses marks it as the greatest factor in that definite movement of the materials of the earth's surface from the high toward the low latitudes, which the modern "Doctrine of Isostacy" has sought to explain by a reverse movement underneath and a subsequent elevation[1].

The study of the torrents of Switzerland and Italy suffices to show the size of individual blocks which may be moved along the bed of a stream[2] or even carried freely in suspension. The burden of detritus brought down in the middle and side moraines of the Unteraargletscher in the Bernese Oberland is spread over a wide area by the headwaters of the Aar River, forming a waste of heavy boulders and coarse gravel covering $\frac{1}{2}$ square mile. Through this wilderness of stone, the milky waters of the river find a tortuous path, carrying in suspension to the Lake of Brienz below the particles of powdered rock ground from the sides of the valley by the daily motion[3] of the glacier. It is the presence of this so-called "gletschermilch," which gives to the Swiss lakes a part of their peculiar and beautiful coloring.

These short but destructive torrents divide themselves naturally into a "sammelgebiet or erosionsgebiet," where the water and solid material is gathered, the "gebiet des murgangs"[4] forming a canal

[1] Compare "Theory of the Earth's Rotation and its Interior Heat," pp. 26–32, Elon Huntington. Rochester, N. Y., 1895.

[2] For a graphic description of the descent of material in a mountain torrent, see Lechalas, "Hydraulique Fluviale," Annexes, pp. 424–428.

[3] The Unteraargletscher has a velocity down the valley of 0.50 m. per day. It was here that Agassiz made his glacier measurements. The Rhône Glacier, separated from the valley of the Aar only by the Nägelisgrätli divide, has a daily velocity of 1.0 m.

[4] For examples of dangerous "murgänge," read Riedel's "Ueber Geschiebe Führung und Murgänge der Wildbäche." *Zeitschrift des Oesterrich-Ingen- und Arch.- Vereins*, 1871, pp. 113 and 151.

through which the semi-fluid mass passes at considerable velocity and with little deposit, the "ablagerungsgebiet," where the solid material is deposited in the main valley, forming a clearly defined cone, with its apex at the point where the torrent issues from the mountain. Lastly, the "ablauf"[1] or bed through which the water, relieved of the mass of its burden, finds its way to the main water course.

A photograph, taken during the summer of 1895, shows clearly these lines of demarcation in the two torrents close above Guttannen on the west side of the lower Haslithal. The axis of each is approximately at right angles to the Aar, into which they discharge. At the foot of this same valley on the eastern slope, above Brienz, lies the small Swiss village of Neuschwanden. At its edge, through an abrupt chasm in the mountain side, and so close as to render the danger to the village an imminent one, issues the cone of dejection of the Lammbach, probably the most destructive in Switzerland. The huge mass of stone and boulders covers a fan-shaped area of approximately a square mile and is largely devoid of vegetation. The slope is nearly uniform from the apex to the banks of the Aar, which it has forced against the further side of the Haslithal. An approximate measurement, made by the author in August, 1895, showed this slope to be about 8 degrees. At that time the side toward Neuschwanden was overlaid with the fresh "murgang" or lava-like mass of gravel and boulders of the preceding autumn which had formed a semicircular cordon about the village and was only deflected from the houses by heavy guide walls. The upper surface is nearly plane and the stream does not, as might be expected, thin out gradually to the edges. It forms a bed of nearly uniform thickness, forking into various divisions at the apex of the cone, while each edge is sharp and clearly defined, marking an abrupt descent to the bottom. In general one may liken the form of these streams to that of those beds of broken stone carefully arranged in prismoidal form one sees in American cities.

That something of an analogous nature takes place in all larger water courses is certain. The difference is one of degree and not of kind. The variance of opinion among authorities now hinges on the ratio between the total amount so moving, in a given river, and the amount carried in intermittent or permanent suspension.

[1] The French writers use only the first three divisions and the corresponding terms "bassin de réception," "canal d'ecoulement" and "cône de déjection."—See Surell, "Etude sur les Torrents des Hautes-Alpes." Paris, 1870-72, Dunod.

Piles driven up stream from a caisson of the St. Charles Bridge over the Missouri are said to have been found under the caisson when it reached bed rock.[1] Jas. B. Eads describes the sand on the bed of the Mississippi at the St. Louis Bridge as moving for at least 3 ft. in depth, with a velocity decreasing below the surface.[2] A pile embedded upright in the sand has been seen to move bodily down stream.[3] The velocity of movement in this sense has been determined by means of stakes driven in the bed of the Loire.[4] Other recorded cases are numerous and need not be multiplied here.

The transportation of coarse gravel in free suspension is but another order of the same phenomenon. It has been observed in the Garonne, when dikes have been broken through, and gravel, borne in the upper laminæ of the current, has been carried over the breach and deposited in the fields beyond.[5] In a similar case, masses of gravel were carried over a dike below Pittsburgh[6] and deposited down stream, filling up hollows which had previously existed there.

The law of decrease in mean velocity from the rise to the embouchure of rivers is closely followed by the steady decrease in size of the particles forming its bed and strewn along its banks. The ratio between the amount of solid matter entrained and that of the liquid at any point in a stream has been called by M. Fargue its torrential coefficient. This should decrease from source to mouth with the fall and the mean velocity. M. E. Charlon[7] has made use of the law in the deduction of a formula, by means of which he computes the velocity of a stream from the size of the materials transported by it. The question of corresponding decrease in amount of suspended matter, per cubic foot of water, is a disputed one. M. Fargue[8] holds the view that rivers become more and more muddy toward their embouchures, due to the accumulated transformation of the coarse into fine materials by friction. M. Partiot,[9] on the contrary, states that 300 measure-

1 "The Mississippi as a Silt Bearer." R. E. McMath. *Van Nostrand's Engineering Magazine*, Vol. XX, 1879, p. 227.

2 "Report of Chief Engineer of St. Louis Bridge." J. B. Eads, June, 1868, p. 21. Quoted by R. E. McMath in above paper

3 *Engineering News*, Feb. 9, 1884, p. 65.

4 See Partiot. "Les Sables de la Loire," p. 43.

5 The same, p. 23.

6 "Report of Chief of Engineers, United States Army," 1876. II, p. 5.

7 See *Le Génie Civil*, Vol. XVII, 1890, p. 170. Note giving formula in *Proceedings* of the Institution of Civil Engineers, Vol. 102, p. 350.

8 "Etude sur la Largeur du Lit Moyen de la Garonne," pp. 12, 13. M. Fargue. *Annales des Ponts et Chaussées*, October, 1882.

9 "Mémoire sur les Sables de la Loire." M. Partiot, p. 21.

ments in the Loire, during the floods of 1856, showed the turbidity to decrease regularly toward the sea. Measurements continued throughout the flood showed, proceeding down stream, the weights of sediment per cubic meter of water to be—

At Feurs ....300 grs.	At Nevers ...210 grs.	At Tours.....212 grs.
Roanne...242 "	Gien .....223 "	Saumur...177 "
Digouin ..191 "	Orléans ..237 "	Nantes....150 "

M. Partiot explains the anomalies shown between Nevers and Orléans by the entry, between those points, of tributaries heavily charged with silt.

A comparison of various measurements in the Mississippi was undertaken by the author. The results would seem to bear out M. Partiot's view.

The available data are the Carrollton and Columbus measurements of 1851 and 1858, the measurements of 1879, at Helena and at St. Louis.[1] The two former were taken during floods. The two latter at a medium stage. The Columbus measurements represent only surface specimens. The Carrollton samples were taken with a defective apparatus. These facts render it impossible to draw any conclusions from a comparison of the 1851 and 1858 results with those of 1879, which seem more reliable.

However that may be, a mean of the results at Columbus and at Carrollton, from the second week of March to the second week of November of their respective years (1851, 1858), shows the proportion of sediment to water, by weight, to be—

Columbus	.000749
Carrollton	.000601

an evident decrease in sediment at the lower station.[2]

There is an apparent co-ordination between the two 1879 measurements which gives more weight to the results obtained. Taking the mean only of the top and bottom measurements, as no mid-depth quantities were taken at Helena, and covering the period from April

[1] See a valuable article by R. E. McMath, in *Van Nostrand's Engineering Magazine*, Vol. 28, 1883, p. 33.

[2] During these measurements the mean velocity of the river ranged at Carrollton from 6 to 1.7 ft. per second, and at Columbus from 8 to 1.5 ft. per second, being, as a whole, considerably higher at Columbus.

10th to June 18th, 1879, at Helena, and April 14th to June 25th, at St. Louis, the proportions of sediment to water, by weight, are—

St. Louis	.002046
Helena	.001079

a much greater decrease toward the river mouth.[1]

The law cannot be demonstrated from the measurements now available. That the effect of interaction among the solids moved on the bed should show a cumulative effect in the increased number of fine suspended particles down stream is to be expected, and is shown in Nature by the increased fineness of the deposits. That it should manifest itself in an increased weight of suspended matter per cubic foot, as held by M. Fargue,[2] does not appear to be substantiated by the limited number of observations at hand.

The question is: Will a stream moving at a given velocity sustain a greater weight of fine particles per cubic unit of water than of large ones of the same density? If so, then a heavier load per cubic foot may be carried at the embouchure of rivers with the same expenditure of energy than in their higher reaches.

Mr. G. K. Gilbert [3] has shown that the same consumption of energy will hold in suspension a greater load of fine than of coarse material of like density.

This may be shown as follows: Assume a stretch in the lower course of a river bounded by the cross-sections *A* and *B*. Assume the kinetic energy at the two points to be the same, so that the whole gravity work done by the weight of the stream in its descent is used up in external and internal frictional resistance. Suppose an inch cube of stone introduced at the surface at *A*. The total energy of the stream has now been increased. The cube reaches the bottom at *B*. It can only act on the bed between the two points by pressure, but as the friction on the bottom is independent of fluid pressure, this friction is not increased. If the cube sinks at the same rate it would have chosen in quiescent water, it makes no demand upon the energy of the

[1] At Helena, the mean velocity ranged from 4.26 to 3.23 ft. per second, while at St. Louis it varied from 7.21 to 4.0 ft. per second, averaging considerably higher than at Helena.

[2] M. Fargue says ("La Largeur du Lit Moyen de la Garonne," p. 13): "Il s'opère donc, de l'amont vers d'aval, une transformation dans la qualité et dans le mode de transport du débit solide: le débit en gros matériaux traînés sur le fond, qui n'a lieu que sous l'influence de vitesses notables, va en diminuant; celui des matériaux ténus, en suspension dans l'eau et obéissant aux faibles vitesses, va au contraire en augmentant. * * * les eaux deviennent en effet de plus en plus vaseuses à mesure qu'on se rapproche de la mer."

[3] *American Journal of Science*, July and August, 1876, Part II; also abstract in *Engineering News*, August 19th, 1876.

stream. If it sinks more slowly, the difference between the distance actually sunk and the distance which would have been covered in quiet water during the time of transit from *A* to *B*, multiplied by the weight of the cube in water, measures the demand upon the stream's energy.

Suppose the same stone to be pulverized into small cubes and again introduced at *A*. The weight in water is unchanged. The draft upon the stream's energy between *A* and *B* is computed in the same way as before and found to be less, because the difference between the distance sunk in quiet water and in the actual case is less. The reason why the small particles sink more slowly is because the collective area at right angles to the motion is greater, and so requires a smaller value of the velocity of sinking in order to keep the total resistance to motion,

$$P = k \gamma F \frac{v^2}{2g}$$

a constant in the two cases. This is required because the work done by the cube in sinking to the bottom must be the same as that done by its component parts in covering the same distance.

It is shown, then, that a less consumption of the stream's energy between *A* and *B* is required to suspend the same weight of small particles than where the grains are of the same density and larger size. It follows that the same expenditure of energy will suspend a greater weight of the small particles per cubic foot of water.

This may offer an explanation of the phenomenon observed at Columbus and advanced by General Abbot[1] to prove that no relation exists between velocity and weight of sediment per cubic foot of water. He states that the Ohio and Missouri Rivers move side by side at Columbus in the bed of the Mississippi without mingling their waters, and that, while their velocity is common, the Ohio water has only three-fourths as much sediment per cubic unit as the Missouri water.

If they are actuated by the same velocity it may be assumed that there is the same amount of energy per cubic foot in each case diverted to the suspension of sediment. The sediment of the Missouri is much more comminuted than that of the Ohio, as shown by the appearance of the two streams. An excess in weight of sediment per cubic foot is to be expected, then, in the Missouri water, as the measurements showed, even though the velocity is the same in both.

[1] *Van Nostrand's Engineering Magazine*, Vol. XX, 1879, p. 3.

The problem now becomes one dependent upon the circumstances of each case. If the energy available for the work of suspension per cubic unit of water is the same at the mouth as at the head waters of a stream, the weight of sediment per cubic unit will be greater. This excess will diminish and finally become negative as the ratio of the available energy at the mouth and head waters becomes less.

In general, it would seem that the available energy should decrease rapidly toward the embouchure and be accompanied by some slight decrease in the weight of sediment carried per cubic foot of water.

1. Minor Agents Influencing Sedimentation.

Temperature.—Chemical precipitation, in general, takes place more easily at higher temperatures. The same law appears to obtain in the case of matter in mechanical suspension. The author's attention was first directed to the question by Mr. Allen Hazen, of Boston, who had noticed an appreciable increase in deposition of suspended matter at higher temperatures in the sewage at the Lawrence, Mass., Experiment Station. Bouniceau[1] and Partiot[2] are agreed that river deposits are greater in summer than in winter. The sediment observations of Prof. Riddell[3], and those of Prof. Forshey[4], at Carrollton, on Mississippi water both give corresponding temperatures. The former lasted from May 21st to August 13th, the temperature gradually rising from 72° to 84° Fahr. The corresponding amounts of suspended matter show an irregular but still perceptible decrease. They follow, however, much more closely the fluctuations in the river surface above low water, so that the element of decreased depth and consequent decrease in velocity of flow enters in as a more potent factor in producing the same result.

The sediment curves at both Columbus and Carrollton[5] seem to show an increase in suspended matter during the summer months of June, July, August and September, the temperature of the river water at Carrollton reaching a maximum of 86° Fahr. in August and descending very regularly to a minimum of 39° in February.

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1 "Etude sur la navigation des rivières à marées." M. Bouniceau, 1845. Quoted in *Proceedings* of the Institution of Civil Engineers, Vol. 66, p. 5.

2 "Mémoire sur les Sables de la Loire," p. 22; M. Partiot. *Annales des Ponts et Chaussées*, I, 1871.

3 "Report to American Association of Geologists and Naturalists, 1846. Quoted by Humphreys and Abbot, "Report on Mississippi River," p. 142.

4 "Report on Mississippi River," Humphreys and Abbot, pp. 134, 148.

5 The same, Plates XII and XIII.

It is evident that river observations are little fitted for the study of this question because of the complexity of the elements involved in fluvial motion. A simple laboratory experiment on the length of time acquired for mechanical precipitation in quiescent water under different temperatures would determine the matter. The yearly range in temperature in rivers is not great, and its influence on sedimentation will be very limited. In the case of flow in sewers it may assume more of practical importance.

A large number of different measurements in the Elbe[1], made under various conditions, failed to show any change in temperature with depth. In the Mississippi River the difference between surface and bottom temperatures is usually too small to be registered by an ordinary thermometer. The maximum difference is a small fraction of a degree.[2]

Herr Blohm[1] has assigned an important place among the causes of suspension of finer particles to a system of circulation set up by the differences in temperature. He calls attention to the fact that water reaches its greatest density at 3.5° R. (39° Fahr.) and that laminæ at a less temperature than this would tend to rise to the surface, as well as those at higher temperatures. The result would be a mixture tending to produce the uniformity actually observed at all depths. The tendency of the warmer laminæ to rise would be equal, in his opinion, to the tendency of the finer particles of sediment to sink in obedience to gravity.

The Mississippi may be taken as an index of the rivers of the temperate zones. Its waters at Carrollton during two years' observations never exceeded the temperature of maximum density, so that, in this case at least, there could have been no circulation, from this cause, of colder water from below to the surface as an equalizer of temperatures.

Light.—The slight molecular agitation caused by the penetration of light has been shown to be sufficient to affect the rate of sedimentation in quiescent water. Mr. Andrew Brown[3] found that a phial of turbid water had a uniform tendency to deposit its sediment most

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[1] "Ueber die in fliessenden Wasser suspendirt enthaltenen Sinkstoffe," Blohm. *Zeitschrift des Architekten und Ingenieur-Vereins*, Hanover, 1867, pp. 277–278.

[2] Lieutenant Marr in "Report on Mississippi River," Humphreys and Abbot, 1876, p. 149.

[3] *Proceedings* American Association for the Advancement of Science, 1848; also, Humphreys and Abbot's "Report on the Mississippi," 1876, p. 144.

rapidly in the portions protected from the light, the surface of the deposit showing a corresponding inclination.

Viscosity.—At low water, under a hot sun, M. Partiot[1] has seen the rising tide, at the embouchure of the Loire, float off patches of sand from the bars and carry them upon its surface so long as it remained undisturbed by waves. A similar phenomenon is noted in the *American Journal of Science*, December, 1890.[2] Blotches of sand, 1 in. in diameter at first, which later joined themselves into 6-in. squares, were eroded from a bank forming an angle of 150° with the water surface. These were seen floating on the surface half a mile down stream, and, if disturbed, would rapidly sink to the bottom. An oiled needle will float on the surface of water if carefully placed in position. Phenomena of this nature are due to what may be called superficial viscosity, which has a greater intensity than the viscosity in the interior of the fluid.

That this latter influence has a part in the suspension of sediment is shown by the length of time required for quiescent turbid water to clear itself. Experiments showed turbidity in water taken from the Garonne after eight days and muddy water from the Elbe made no perceptible deposit until after a lapse of 24 hours.[3] In water taken from the Mississippi at St. Louis in 1865, Mr. Flad[4] found that for a total of 1 000 parts in suspension at the beginning of the experiment,

944.50	parts had settled during the first	24 hours.
22.35	" " " " " second	24 "
2.92	" " " " " "	48 "
30.23	" were still[5] in suspension after	96 "

Changes in viscosity and consequent suspending power are a probable concomitant of changes in temperature.

Salt Water.—Observations made in 1839 by Sidell[6] at the mouths of the Mississippi showed that the river water alone required from 10 to 14 days to settle. The admixture of salt in any form reduced the time of settling to between 14 and 18 hours. Mr. Gould[7] found that a few

1 "Sables de la Loire," p. 36.
2 Noted in *Engineering Record*, December 27, 1890, p. 65.
3 Blohm in *Zeitschrift des Architekten- und Ingenieur- Vereins*, Hanover, 1867, p. 245.
4 "Silt Movement by the Mississippi," R. E. McMath. *Van Nostrand's Engineering Magazine*, 1883, p. 33.
5 Since the present article went to press the author's attention has been called to an article by Mr. Carl Barus (Bulletin No. 36 of the U. S. Geological Survey), in which he shows that a degree of comminution can be secured such that deposition will never take place.
6 "Report on the Mississippi River," 1876. Appendix A, p. 500.
7 "Report of Chief of Engineers, United States Army," 1875, II, p. 36.

pinches of salt thrown into a tumbler containing muddy water from the bottom of the Savannah River caused a much more rapid deposit. Mr. Fargue[1] has found that the same amount of mud introduced into a glass of fresh water and into a glass of salt water shows a difference in the period of settling. The salt water is clear after six hours of repose. To attain the same result requires eighteen hours in the fresh water.

This property of saline solutions has an important bearing on the formation of bars at mouths of rivers discharging into salt seas. The load of detritus will be dropped sooner than if the receiving body were fresh water.

Action of Waves.—The formation of bars in deep water at the mouths of tidal estuaries has in late years come to be attributed to wave action upon the detritus discharged by the river rather than to the simple process of deposition itself. It is the dynamic effect of the waves which heaps up the bars.[2] All sea beaches show this action so clearly that there can be little doubt as to its influence, in a lesser degree, on the movement of detritus in rivers. Observation has shown that sands are often moved when the bottom velocity is such as to be an insufficient cause. Mr. P. O'Meara[3] has observed this motion by diving to the bed of a tidal channel where the bottom velocity was too slight, unaided, to move the sands. He found that the sand at and near the bottom, under a depth of 10 ft., had an oscillatory motion corresponding to the 6 and 8-in. waves passing above. At the center of the wave passage the sand reached a considerable velocity; at its end the motion ceased and even seemed to be reversed. He holds that this action may be perceptible to depths of 40 or 50 ft. Waves of translation stir the water to an infinite depth, theoretically, their velocity of translation being dependent upon the depth. Such waves will be confined to tidal estuaries. Waves of oscillation, such as the wind ripples in rivers, are felt, however, to considerable depths.

At Cherbourg[4] these waves cease to act on the piers at a depth of

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1 "Étude sur la Largeur du Lit Moyen de la Garonne." *Annales des Ponts et Chaussées*, Oct., 1882, p. 21 (footnote).

2 A formula for the scouring power of waves, giving relation between height of wave and size of particle moved, is developed by Mr. W. Smith in *Proceedings* of the Institution of Civil Engineers, Vol. 100, p. 201.

3 *Proceedings* of the Institution of Civil Engineers, Vol. 118, pp. 84, 85. Noted, also, in *Engineering Record*, Feb. 23, 1895, p. 219.

4 "Les Marées Fluviales," M. Comoy, 1881, p. 23.

about 25 ft. At Algiers the limit is 35 ft. There the sands cease to be moved at depths between 50 and 100 ft., while the limit for muds is 450 ft. A visit to the harbor of Algiers during a heavy blow showed its peculiarly exposed position so that these figures may be reasonably considered maxima.

Action of Ice.—The removal to great distances of boulders which neither ordinary nor flood velocities could move has been attributed to the transporting power of ice. There is a tendency in rivers to form what is called anchor ice at the bed and sides when the water is shallow. This ice attaches itself to the solids in its vicinity, and, because of its slight specific gravity, is easily detached by flood velocities and carried with its load down stream. M. Partiot[1] calls attention to this action on sand shoals barely covered by water from which the surface layer is detached by the floating away of the ice.

Action of Sediment in Diminishing Velocity.—Mr. Baldwin Latham reports[2] observations covering a series of years which seem to show that the velocity of turbid water for the same depth and fall is less than that of clear water. He holds that this difference bears a ratio to the amount of turbidity, and is caused by the work used in transporting the material. The discharge of clear water multiplied by its velocity corresponded closely to the combined weight of sediment and water in the corresponding case, multiplied by its mean velocity. Mr. G. K. Gilbert has reached the same conclusion.[3] He states that the total energy of a clear stream is used up in friction on its bottom; that this friction is directly proportional to its velocity. When detritus is carried a certain amount of the energy of the stream is used to keep it in suspension, and this takes place at the expense of friction and consequently of velocity. It is to be remembered, however, that the total energy of the stream has, in the meantime, been increased by the addition of the energy represented by the vertical fall of the solid particles.

The law of the conservation of energy will not admit of any other

[1] "Les Sables de la Loire," p. 36.

[2] *Proceedings* of the Institute of Civil Engineers, Vol. 71, p. 46.

[3] "The Colorado Plateau Province as a Field for Geological Study," *American Journal of Science*, July and August, 1876. Part II. Abstracted in *Engineering News*, August 19th, 1876.

decision in this matter, though the statement has sometimes been made that such a retardation of velocity does not exist[1].

Mr. Gilbert's statement that the work done by a clear stream is entirely used up in friction on the bed is somewhat at variance with the attitude of the best science of the present day.[2] The energy consumed by intermolecular resistances caused by the complex motion in the interior of the liquid is much greater than that actually used at the earth and air profiles. It should be added, however, that these intricate movements are induced by the bed's rugosities. In general, it may be said, that the total energy is used in friction, through which it is transformed into heat energy.

Assume a portion of a clear stream between the sections A and B. Suppose no difference of kinetic energy between the two stations, then the total energy of the stream expended is used in work done on friction. Introduce a mass of sediment in suspension at A and a demand

[1] See "Silt Movement by the Mississippi," R. E. McMath. *Van Nostrand's Engineering Magazine*, 1883, p. 36. Mr. McMath says: "We have seen that transportation of silt (up to the point of impaired fluidity) is not at the expense of the stream's motion. The work of erosion and suspension is done by the stream, whose velocity must be diminished compared with flow under a like head in a smooth channel, but if the now-yielding bed should suddenly become rigid, the same or even greater force would be expended upon the obstructing roughness. Therefore though suspension consumes a part of the stream's force the velocity is not necessarily lessened beyond what it would be in the only alternative condition that can be considered, a rigid bed equally rough." This line of reasoning would seem to hold, so far as the actual work done upon the bed of the river between any two points is concerned. The work which would have been expended upon a rigid bed equally rough is now in part expended upon the mobile bed in the same way as before, while the residue is free to be used in carrying into suspension whatever is eroded from the bed between the sections considered. But this theory fails to take account of those external forces of Nature which are continually wearing away cliffs, disintegrating hillsides and introducing at the surface of the stream a mass of debris to be carried, for which the stream's own mechanical action is not accountable. Gravity acts as an external force where banks cave in and throw upon the stream's energy an additional burden. The burden already in suspension at the entrance to the stretch considered must be carried in addition to that considered by this theory. It is to this additional burden that a consumption of energy and consequent retardation of velocity may be attributed.

[2] See Boussinesq "Theorie des Eaux Courantes," Paris, 1872, introductory chapter. M. Boussinesq has shown that neither the friction, rightly called, upon the bed nor the added internal friction due to relative velocities of parallel filaments following stream lines is sufficient to explain the transformation of the energy of the stream, in its descent, into heat energy. He shows that if the velocity at the walls were assumed to be zero so as to attribute the whole work to friction between parallel filaments, the coefficient of interior friction is so small that the central filament, in a semicircular conduit of 1 m. radius and a fall of 1 in 10 000, would acquire a velocity of 187 m. per second before equilibrium was established between the accelerating force and the fluid resistances. It is, then, to the vortices that must be attributed the largest share in this transformation. They largely increase the total interior friction.

See "Journal de M. Lionville," t. XIII, 1868. Also "Theorie des Eaux Courantes," Boussinesq, pp. 2-6.

Compare, also, Prof. Unwin in "Encyclopedia Britannica," article on Hydromechanics.

is made on the stream's energy to keep it suspended to B. The thought at once suggests itself that the total energy has, in the meantime, been increased. In answer, it may be said that the addition has also increased the friction at the bed since the formula

$$P = k\, F\, \gamma\, \frac{v^2}{2g},$$

shows this friction to be a function of the heaviness of the fluid, which in its new compound state has been increased. These two changes tend to counteract each other and to leave still an increased demand upon the energy originally used in the passage from A to B. In consequence, there will result a retardation of velocity at B accompanied by an increase of depth if the supply be constant. For particles of a uniform size and density, this decrease in velocity will increase with the weight of the load per cubic unit of water. The decrease will be less for a given weight of fine particles than for the same weight of large ones, other conditions remaining the same.

The presence of silt, then, retards velocity in two ways:

First.—It uses an amount of the stream's energy in suspending it.

Second.—It increases the heaviness of the composite fluid and so increases friction.

2. Influence of Depth on Transporting Power.

It was once believed by hydraulicians that the adhesion between a liquid and its bed was stronger than the internal cohesion of the fluid itself. It seemed the natural deduction from the decrease in velocity observed near the banks and bed. The hypothesis then took form that the particles next the banks remained stationary, while the main current flowed by in a fluid bed of its own consistency.[1] The experiments of Darcy on deteriorated pipes showed that velocity was a function of roughness, and the incorrectness of the former assumption. Even the outermost particles of the fluid substance have a motion relative to the bed. Is this velocity influenced by the depth? Increased depth means increased weight per square unit of bed, and consequently increased pressure, but experiments have shown that not only the coefficient of fluid friction, but also the friction itself, is independent of the pressure.[2]

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[1] This has been shown to be true for capillary tubes by M. Duclaux, of Clermont. See *Annales de Chemie et de Physique*, 4e Série, t. XXV, 1872. For flow in streams and large pipes it appears inadmissible.
See also "Theorie des Eaux Courantes." J. Boussinesq, pp. 1–2.

[2] "Encyclopedia Britannica," Article Hydromechanics.

In the case of a homogeneous solid sliding down an inclined plane the coefficient of sliding friction is independent of the normal pressure, but the friction itself

$$P = f\,N \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

is a function of both quantities, and remains unchanged at all velocities. The liquid prism, sliding down an inclined bed, acts according to other laws so far as frictional resistance is concerned. Here again,

$$P = (k\,\gamma)\left(F\frac{v^2}{2\,g}\right)$$

or

$$P = f_1\,N_1 \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

an equation of the same form as before, but made up of quantities formed in a different way. In equation (1) N represents the normal component of the body's weight, is proportional to depth when the prism is homogeneous, and is independent of velocity. In (2) N_1 again represents weight, but this weight is directly proportional to a velocity height, and is independent of depth. Increased depth, velocities remaining constant throughout, will have no effect on friction and hence produce no change in scouring action.

The case is sometimes cited, as a substantiation of the view that depth increases transporting power for the same velocity, of the increased difficulty in wading a deep stream. The example is not a good one. A man's foothold is lost sooner in this case than in a shallow ford because of his increased loss of weight rather than from an increase of transporting power, properly called.

The statement has been made[1] that in practice observation shows the scouring power of a shallow stream at a high velocity to be much less than that of a deeper river running at a slower velocity. The explanation offered by Prof. Unwin[2] would seem to account for a portion of this difference. He attributes to the deep stream the advantage that the particles of its bed may be thrown up to a greater height, and, since the velocity of descent again to the bed should be the same in both cases, will be thus carried farther down stream before being deposited.

Flood waters offer great variations of depth which may be used in the determination of comparative amounts of sediment per unit volume.

[1] See *Proceedings* of the Institution of Civil Engineers. Vol. 82, 1884, p. 31.

Mr. Law's explanation of the phenomenon is based on the incorrect assumption that fluid friction increases with pressure.

[2] "Encyclopedia Britannica," article Hydromechanics.

These weights will vary for the same depth with the relative stage of the flood, and so complications are introduced. The earlier stages of a heavy rainfall wash down the surface particles loosened by weathering. The later portion of the storm finds a more resisting surface. M. Partiot found traces of this fact in the relative weight of sediment at different stages of the same flood. A safe basis of comparison would seem to be the same relative stages of floods of different heights when the same tributaries are discharging high water.

M. Partiot[1] has been able to detect only a slight increase in the sediment per unit volume in the Loire, with the importance of the flood. M. Fargue[2] states that the suspended sediment is very feeble at low water and reaches its maximum intensity at the flood crest.

Major Allan Cunningham[3] bases the statement that no relation exists between depth and silt intensity, upon a series of observations on the Ganges Canal.

A study of the data at hand will throw the most light on the subject. Fig. 1 gives a graphic representation of data bearing upon this point. Further curves might be added from the extensive measurements of the Mississippi Commission[4] made in 1879–81 at Carrollton, Prescott, Winona, Clayton, Hannibal and St. Louis. The Carrollton and Columbus sediment ordinates are taken from the "Report on the Mississippi" by Humphreys and Abbot, page 417—one for each week of the year. The corresponding mean gauge readings were taken from Plates XII and XIII of the same volume. The St. Louis co-ordinates are from Mr. McMath's paper in *Van Nostrand's Engineering Magazine*, 1883, page 33. The Helena co-ordinates are from the "Report of the Chief of Engineers, United States Army," 1879, Part III, page 1968. The Elbe and Maas measurements are taken from the *Zeitschrift des Architekten und Ingenieur Vereins*, Hanover, 1867, pages 290 and 291.

The method of plotting these curves must be distinctly understood. They start from no common origin. They have no quantitative relation to each other. Each represents only the general trend of direction of the number of points from which it is constructed. These are in most cases widely scattered, but their general direction is clearly defined and

[1] "Sables de la Loire," p. 22, 1871.

[2] "La Largeur du Lit Moyen de la Garonne, p. 14, 1882.

[3] See *Proceedings* of the Institution of Civil Engineers, Vol. 71, 1882, p. 35. "Roorkee Hydraulic Experiments."

[4] "Report of Chief of Engineers, U. S. Army," 1883, III, pp. 2209 and 2266.

is fairly represented by the lines shown. It is seen at once that their direction, in each case, is such as to show an unmistakable increase in sediment per cubic foot with higher stages.[1] Each is independently constructed and all show the same thing.[2] The author can find no other values to contradict them.[3] This seems to show satisfactorily that weight of sediment per cubic foot increases as the river rises and depth increases. That it proves that transporting power in-

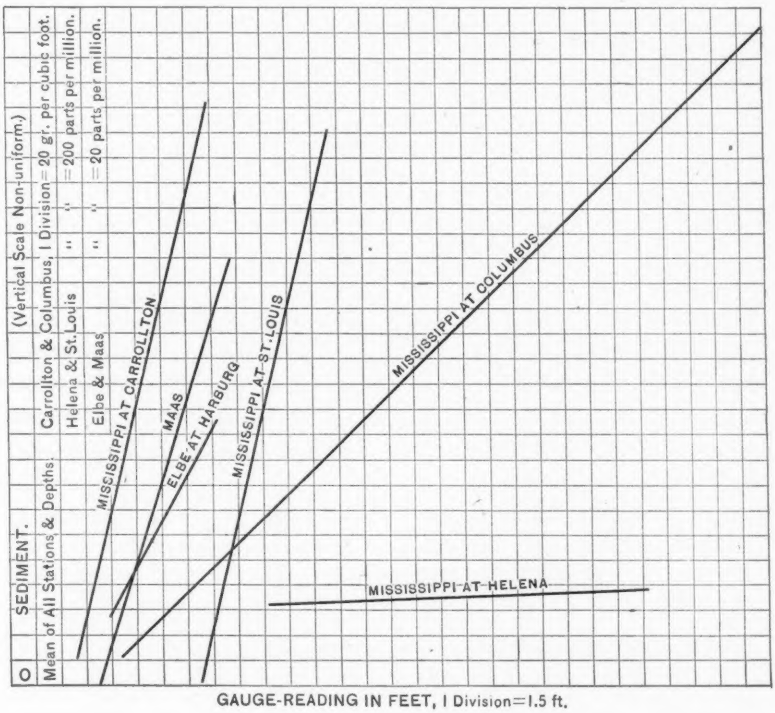

FIG. 1.

creases with depth is not claimed, for velocity increases with stage also, and either one or both together may be the cause of increased

[1] In the curves shown on Plate VIII of the "Report of the Mississippi River Commission," 1879–81 (see "Report of the Chief of Engineers, United States Army," 1883, III), this relation is only slightly traceable in the Carrollton measurements of 1879–80.

[2] Since the above curves were plotted the author has found a plate showing a series of points plotted in an analogous manner from the extensive observations of Assistant Engineer Seddon at St. Charles, Mo., 1879 (see "Report of the Chief of Engineers, United States Army," 1887, Part IV, pp. 3090–96. For description of apparatus used see same report, pp. 3121–23). These points show how a curve similar to those in Fig. 1 could be drawn and are clearly confirmative of the conclusions here deduced.

[3] The results of Prof. Riddell's measurements are confirmatory. See Humphreys and Abbot's "Report on the Mississippi," 1876, p. 142.

transport. If, however, one were to join with Humphreys and Abbot in denying any fixed connection between velocity and suspending power, then this might be looked upon as proof.

The influence of a gradual or sudden decrease in depth upon transporting power offers a range of experiment and observation which is yet to be made. There is little definitely known from measurements about the influence of such shoaling upon the curve of velocities. For unchanged width, decrease in depth means decrease in sectional area and consequent increase in mean velocity for constant discharge. Such a shoaling may be likened, in its action, to a submerged weir. When the change is sudden there will be a mass of dead water above the weir, at the bottom, forming a fluid bed upon which the discharged water flows. This would seem to indicate conditions favorable for a deposit above the obstruction, upon the same principle upon which Humphreys and Abbot explained the formation of delta bars by deposits in the dead angle caused by the fresh water flowing over the heavier salt water.

The case of movable dams in many of the continental rivers is in point. Experience, however, fails to show any shoaling of consequence above these structures.[1] The natural conclusion is that this dead water, so called, must be in a lively state of agitation, its eddies and vortices carrying up deposited material to the higher laminæ whose movement of translation carries it over the obstruction.[2]

In a gradual shoaling, with banks widening to form a pool, there is no sudden accession of vortex motion and the decrease in velocity due to enlargement of section is followed by deposits until equilibrium is established between the velocity of the stream, the resisting power of the banks and that of the bed.

The question of changes in the form of the curve of velocities, as affected by obstructions, is still in need of experimental research by measurements made at varying distances above the obstruction to determine the velocities throughout the range of the back-water.

That the friction of the air has some effect in influencing the form of this curve has been generally accepted since the Mississippi measurements were made. It is only the extent of the influence which was then claimed for this factor which has since been called in question by

[1] For substantiation of this statement see Flamant, *Annales des Ponts et Chaussées*, 1882, quoted by Lechalas, "Hydraulique Fluviale," 1884, p. 64.

[2] See "Report of the Chief of Engineers, U. S. Army," 1876, II, p. 5.

those who have other theories for the cause of the depression of the maximum velocity below the surface.[1] That its retarding effect is less than that of the friction on the bed is usually conceded.

That both are greater than the internal friction due to laminated flow is a reasonable conclusion from the actual form of the vertical curve of velocities, substantiated by Boussinesq's demonstration[2] of the slight value of this friction of laminated flow.

Suppose any cause produces a sudden increase of roughness in the bed and so increased bottom friction. If the hypothesis of parallel filaments[3] is adopted as representing the general trend of flow, the natural conclusion is that the parabolic curve of velocities in a vertical will be tipped down stream. In other words, the lower filaments will be more retarded than the upper ones. That a gradual shoaling with a corresponding increased surface fall has the opposite effect on the curve of velocities has been shown by Dupuit[4] for the case of unchanged width.

There, by a simple numerical calculation, the bottom velocity is shown to take on a much more rapid increase than the surface velocity, so that, at the crest of the shoaling, they have become more nearly equal than before. In the contracted section below the crest the curve will have been tipped up stream, though the rapid increase of bottom friction (varying as the square of the velocity) will soon force it back to the normal position for steady flow at that velocity. He attributes to this disproportionate increase in bottom velocity with the mean velocity, the larger part of the scouring action seen immediately down stream from hydraulic constructions. This view would seem to throw additional light on the cause of non-shoaling above submerged weirs. Experiments are needed on this subject.

3. Influence of Retardation of Velocity.

What, if any, is the relation between velocity and suspension? This is a vital question in the discussion. Assume a sedimentary stream

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[1] See Prof. James Thomson, "Encyclopedia Britannica," Article Hydrodynamics. Also, F. P. Stearns. *Transactions* American Society of Civil Engineers, Vol. 12, p. 331, and Vol. 7, pp. 122–130.

[2] See page 403, footnote.

[3] In spite of the statement often seen, that this in no wise corresponds to the complex motion seen in rivers, especially the Mississippi, an ordinary inspection of streams, even in times of flood, shows it to be more reasonable than any other supposition yet advanced, and to represent, in an average sense, the phenomena observed.

[4] "Etudes sur le mouvement des eaux," 2d Edition' 1863, pp. 58–68.

flowing between regular banks. Does any fixed connection exist between the velocity of the mean of all the cubic feet passing a given section per second and the weight of sediment contained in that ideal cubic foot of water? If so, is the relation one of cause and effect? To the first of these questions Humphreys and Abbot give an emphatic negative,[1] based upon a comparison between the Carrollton and Columbus sediment and velocity curves. Captain Ead's criticism of this view was founded on a misconception.

He proves conclusively in his article that the total weight of sediment passing a given point in the river is proportional to the velocity of the current. This, however, was not the question at issue, and is settled by a moment's reflection. The debatable problem is: Does an increase of velocity increase the transporting power per cubic foot of water passing a given cross-section? The vital question in the problem of jetties is not as to the ability of the contracted stream to carry throughout their length and beyond the sediment contained per cubic foot in the water of the river above. Their success hinges upon the capacity of the stream to take an additional load per cubic foot from its increased velocity until the increasing depth has again established equilibrium. The consensus of opinion of writers seems to answer in the affirmative as opposed to the position of Humphreys and Abbot.

Partiot says[2] that sediment in floods follows the same law as the velocities, increasing up to the highest stage and decreasing afterwards.

Referring to the Missouri, Major Ruffner[3] says:

"The water is so heavily charged with sediment that decrease in velocity is immediately followed by a deposit, but the converse of scour following an increase of velocity, although apparent, is not so well marked nor so extensive. * * * When from any cause the velocity of the current is suddenly increased, the most rapid erosion takes place; and the greatest deposit occurs when the velocity is suddenly checked."

Captain Eads and Mr. Corthell[4] state that the current of the Mississippi cannot be checked in the slightest degree in flood time, when its waters are heavily charged, without causing a deposit; that an

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[1] See p. 378.

[2] "Sables de la Loire," p. 22.

[3] "Improvement of Non-Tidal Rivers," 1886, pp. 78, 138.

[4] *Transactions* American Society of Civil Engineers, Vol. xi, pp. 262, 263.

iron netting, with meshes 1 ft. square, set in a shoal on the Missouri, caused a deposit of 16 ft. in one flood. Mr. Ockerson[1] claims that the river is not always fully charged with sediment and so may at times be retarded to some extent without deposit.

Major Allan Cunningham[2] states that, in the Ganges canal, measurements have shown that silt density is independent of velocity.

Mr. R. E. McMath[3] says the cause of suspension commonly varies with the velocity.

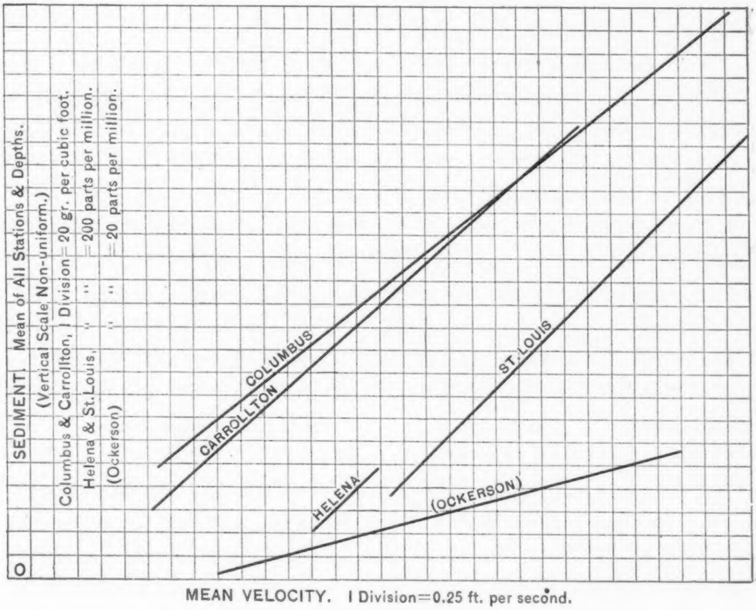

FIG. 2.

These views represent all phases of opinion. General statements are not convincing so it is advisable to analyze the available measurements.

Fig. 2 gives a graphic representation of five different series of measurements in the Mississippi. Other data at hand are unaccompanied by velocity determinations. These curves are plotted with mean velocities as abscissas and amounts of sediment as ordinates. As

[1] *Transactions*, American Society of Civil Engineers, Vol. xi, p. 273.

[2] "Roorkee Hydraulic Experiments." See *Proceedings* of the Institution of Civil Engineers; Vol. 71, p. 35.

[3] "Silt Movement by the Mississippi." *Van Nostrand's Engineering Magazine*, 1883, p. 38.

in Fig. 1 they are not suitable for quantitative comparison. There is no co-ordination in vertical scales. Each represents only the general trend of direction of the points from which it is drawn. The points for the Columbus and Carrollton curves were the most scattering, as would be expected from an examination of the same values plotted in Plates XII and XIII of Humphreys and Abbot's "Report on the Mississippi." There, time is introduced so as to form two curves. Here, a general relation is expressed by one curve, omitting the time element and plotting each observation as a separate point fixed by its sediment and velocity co-ordinates.

An examination of the two curves as plotted by Humphreys and Abbot seems to indicate a relation, especially in the case of Carrollton where samples were taken from three depths and averaged. The relation is not, however, invariable. From the points as plotted here there can be no doubt of the existence of a law.

Another set of measurements was instituted at Carrollton by the Mississippi River Commission in 1879–80 which removes all doubt as to the existence of a relation between velocity and sediment at that point.[1]

The investigations made by this commission at Prescott, Winona, Clayton, Grafton, Hannibal and St. Louis in 1880 and 1881 are the most extensive ever conducted and offer the data for plotting additional curves.[2] Those made by the Missouri Commission at St. Charles[3] in 1879–1880 offer similar facilities.

Of the curves shown in Fig. 2, the most reliable are those representing the Helena and St. Louis measurements because of the improved methods used. In both these cases the law is clearly marked. The curve marked Ockerson is plotted from some measurements published by J. A. Ockerson,[4] M. Am. Soc. C. E.

In Fig. 2 it might seem reasonable to have started each curve from the origin on the ground that stagnant water would carry no sediment. On the other hand, such a proceeding would have been open to objection as an *argumentum in circulo*, and so was avoided. The curves, however, place themselves in a significant arrangement.

[1] See "Report of the Chief of Engineers, United States Army," 1883, III, pp. 2209-2266 and Plate VIII.

[2] These curves have all been plotted by the author and show the same result as those drawn on Fig. 2.

[3] "Report of the Chief of Engineers, United States Army," 1887, IV, pp. 3090-3096.

[4] *Transactions* of the American Society of Civil Engineers, Vol. xi, p. 273. Mr. Ockerson's values for sediment as given above show a marked departure from other determinations in the Mississippi. However, as only the relative quantities are required here, they are used without question.

The curves are believed to show that the sediment by weight in a cubic foot of water does obey a general law of increase with the velocity in the Mississippi River. As such a relation has been largely conceded to exist in other rivers it is believed that it is general. That instant deposit always follow the least retardation is not proved or claimed.

4. Distribution of Sediment in the Cross-Section.

Distribution of Sediment in the Vertical.—Sufficient data is at hand to settle this question in its general bearing. That it has been a matter of dispute is shown by the different opinions expressed.

M. Baumgarten,[1] from measurements in the Garonne, came to the decision that surface measurements were a fair index of the amount of sediment at all depths.

Herr Blohm[2] quotes a number of varying opinions from English, German and Italian engineers; but, from his own measurements in the Elbe at Harburg, finds somewhat of an excess in the surface quantities. He, however, gives it as his opinion that the distribution of sediment is about equal throughout.

Andrew Brown[3] decided, after repeated trials, that sediment in the Mississippi was equally distributed at all depths, provided the samples were taken in the main current.

M. Partiot[4] takes the other view, stating that measurements in the Loire have shown the ratio of surface, middle and bottom quantities to the mean of all, to be represented by the numbers 90, 100 and 110.

M. Surell[5] found that the silt intensity in the Rhone increased rapidly with distance from the surface. He expressed the ratio between surface and bottom amounts by the relation of the numbers 100 and 188.

In the measurements on the Mississippi at Columbus,[6] only surface specimens were used, the ratio 100 to 120 being used to reduce the surface values to the mean for all depths as determined at Carrollton in

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[1] "Navigation Fluviale, Garonne." M. Baumgarten. *Annales des Ponts et Chaussées*, 1842, 2, p. 49. See also page 358 of this paper.

[2] Ueber die in fliessenden Wasser suspendirt enthaltenen Sinkstoffe." Baurath Blohm. *Zeitschrift des Architekten und Ingenieur Vereins*, Hanover, 1867, p. 276.

[3] Humphreys and Abbot's "Report on the Mississippi," 1876, p. 143.

[4] "Sables de la Loire," 1871, p. 24.

[5] M. Guérard on "Mouth of the River Rhone." See *Proceedings* of the Institution of Civil Engineers, Vol. 82, p. 309.

[6] See Humphreys and Abbot's "Report on the Mississippi," 1876, p. 136.

1851–1852, The following table has been prepared from all the data which could be collected upon this matter :

DISTRIBUTION OF SEDIMENT WITH REGARD TO DEPTH.

Place of observation and observer.	Date.	Reference.	PARTS OF SEDIMENT IN 1 000 000 PARTS OF WATER AT THE DEPTHS INDICATED. Surface. (Mean.)	Mid depth. (Mean.)	Bottom (usually 1 ft. above). (Mean.)
Mississippi at St. Louis—McMath	1879	*Van Nostrand Eng. Mag.*, 1883	1 847	2 009	2 117
Mississippi at Helena—Johnson	1879	Rep't Chf. of Eng'rs U. S. A., 1879, III	799	...	1 266
Mississippi at Carrollton—Forshey	1851–52	Rep't on Miss. Humphreys and Abbot, 1861	648	802	842
Sacramento at Kerscheval's—Le Conte	1879	Rep't Chf. of Eng'rs U. S. A, 1879, II	5 525	9 051	5 618
Mississippi at Prescott—Miss. River Com	1880–81	Rep't Chf. of Eng'rs U. S. A., 1883, III	123	157	159
Mississippi at Winona—Miss. River Com	1880–81	Rep't Chf. of Eng'rs U. S. A., 1883, III	34	32	36
Mississippi at Clayton—Miss. River Com	1880–81	Rep't Chf. of Eng'rs U. S. A, 1883, III	40	42	41
Mississippi at Hannibal—Miss. River Com	1880–81	Rep't Chf of Eng'rs U. S. A, 1883, III	165	208	224
Mississippi at Grafton—Miss. River Com	1880–81	Rep't Chf. of Eng'rs U. S. A, 1883, III	319	322	345
Mississippi at St. Louis—Miss. River Com	1880–81	Rep't Chf. of Eng'rs U. S. A., 1883, III	686	906	995
Mississippi at Carrollton—Miss. River Com	1879–80	Rep't Chf of Eng'rs U S. A., 1883, III	"The means of surface, mid-depth and bottom observations are in the ratio of 100, 144 and 183, respectively." Vide Rep't Chf. Eng'r, 1883, III, p. 2216.		
Missouri at St. Charles—Missouri River Com	1879	Rep't Chf of Eng'rs U S. A., 1887, IV	2 418	2 473	2 548
Garonne—Baumgarten	1847	Annales des Ponts et Chaussées, 1848, II	The surface, mid-depth and bottom quantities are in the ratio of the numbers 100, 141 and 125.		
Elbe at Harburg—Blohm	1837–54	Zeitschrift des Arch. und Ing. Ver., Hanover, 1867	Surface mid-depth and bottom quantities are in the ratio of the numbers 100, 93.8 and 98 2.		

A study of the table shows only one case in which the sediment per cubic unit is not greater at the bottom than at the surface. This is that of the Elbe at Harburg. There are two cases where the mid-depth amounts are less than the surface values, the Mississippi at Winona and the Elbe at Harburg. There are three cases where the bottom values are less than those at mid-depth, the Sacramento at Kerscheval's, the Mississippi at Clayton, and the Garonne.

In all other cases there is a marked increase from surface to bottom. When it is considered how extensive a range of measurements is represented in these means and due weight is given to the careful and far-

reaching observations of the Mississippi and Missouri Commissions, it is thought that the law of increase from surface to bottom may be considered as established.

The table shows two other facts. *First,* that surface observations are not an accurate index of the mean amount of sediment. *Second,* that no general coefficient should be used to reduce surface observations to mean values for all depths, since this coefficient will vary in different rivers and for different stages of the same river.

It was hoped that data might be found from which a relation could be established between the form of the velocity and sediment curve in the same vertical. Measurements at all points of the vertical are needed with simultaneous velocity observations at the same depths. The only ones obtained at all partaking of this nature are those in the Sacramento River, which are too limited to be of service.[1] The observations at Carrollton in 1880 showed little change in the surface sediment with change of stage.

Law of Distribution in the Horizontal.—In this study the data available are still more limited. Of the extensive measurements carried on by the Mississippi and Missouri Commissions, the author can find no single case where the samples from the eight positions in the transverse sense were kept separate and the weights published. Mr. Seddon[2] states that nothing of special interest was shown by these measurements at St. Charles, so the data were not published. The Carrollton observations[3] of 1880 are said to have shown a uniform distribution from side to side of the channel and so are not published. Major Cunningham[4] obtained no data from which a law could be predicated in his measurements on the Ganges Canal.

Those at Columbus in 1858 are not printed in detail, but the Carrollton observations of 1851–52 give the single satisfactory set. The measurements made in 1879 by Mr. McMath at St. Louis are not published in detail, but give some facts of interest. The last two sets are represented in the table on the next page by their means for such positions as are indicated.

[1] An article by C. C. Babb, Jun. Am. Soc. C. E., abstracted in *Engineering News*, August 10th, 1893, is said to give curves representing sediment at different depths in the Potomac River.

[2] "Report of the Chief of Engineers, United States Army," 1887, IV, p. 3090.

[3] "Report of the Chief of Engineers, United States Army," 1883, III, p. 2216.

[4] *Proceedings* of the Institution of Civil Engineers, Vol. 71, p. 34, "Roorkee Hydraulic Experiments."

DISTRIBUTION OF SEDIMENT IN THE HORIZONTAL.

Place of observation and observer.	Date.	Reference.	PARTS OF SEDIMENT IN 1 000 000 PARTS OF WATER AT THE POSITIONS INDICATED.		
			Bank.	Middle.	Bank.
Mississippi at Carrollton —Forshey	1851–52	Rep't on Miss., Humphreys and Abbot, 1861	542 (300 ft. from e. bank).....	573	543 (400 ft. from w. bank).
Mississippi at St. Louis – McMath	1879	*Van Nostrand Eng. Mag.*, 1883.	Mean of sediment in the river, 2 062 parts; mean of sediment, 281 ft. from Mo. side, 2 736 parts; mean of sediment 1 291 ft. from Ill. side, 1 523 parts.		

These meager measurements are offered rather to show the need of attention to this matter than as a proof that the maximum of sediment is near the thread of the stream. Mr. McMath[1] found the maximum in nearly every case several hundred feet on the Missouri side of the line of maximum velocity. This could, perhaps, be accounted for by the fact of the Missouri water being more highly charged since its sediment is finer. If the Ohio and Mississippi flow side by side without mingling their waters[2] it may be that a similar phenomenon occurs at St. Louis.

Surface Convexity and the Lateral Movement of Suspended Matter.— It has been stated[3] that crevasses in the Mississippi show a marked swelling or convexity at the thread of the current, where it crosses the levee, and that this convexity, which is due to the excess of velocity, has the effect of drawing floats to a narrow line at the filament of maximum velocity.

Major Cunningham[4] could measure no sensible curvature at the center of the Ganges Canal. He had expected to find such a swelling on the ground that increased velocity would be accompanied by decreased pressure. He quotes the statement of General Rundall that the surface of the Godavery and Mahanuddy Rivers was obviously con-

[1] "Silt Movement by the Mississippi," R. E. McMath. *Van Nostrand's Engineering Magazine*, Vol. 28, 1883, p. 36.

[2] See "Report on the Mississippi," Humphreys and Abbot, 1876, p. 136. Compare, also, the statement made by McMath in "The Mississippi as a Silt-Bearer," *Van Nostrand's Engineering Magazine*, 1879, p. 222. The Missouri water was found to contain 2½ times the amount of sediment carried by the water of the upper Mississippi where the two streams were running side by side, with a common velocity, past Bissell's Point.

[3] "Report on the Mississippi," Humphreys and Abbot, 1876, p. 284.

[4] *Proceedings* of the Institution of Civil Engineers, Vol. 71, pp. 11 and 12.

cave, plane or convex, according as the rivers were falling, stationary or rising.

Mr. Flamant[1] shows that there should be no such difference in pressure since a fluid transmits pressure equally in all directions and the surface should be level for permanent motion. He explains the convexity measured by Baumgarten[2] in the Garonne in one case on the ground that it did not correspond to a permanent state, but to a condition of rise when the center would show the increase before the sides.

M. Baumgarten[3] concludes from his two measurements on the Garonne that the changes are scarcely sensible.

The experiments of Darcy and Bazin[4] showed no results which could be said to express a law.

Prof. De Volson Wood[5] states that the water is highest where the velocity is greatest, but gives no substantiation for the statement.

M. Debauve[6] accepts the idea as true and explains its apparent disagreement with the hydrostatic law on the ground of viscosity, the water tending to the form which will offer the least resistance at the banks.

Major Cunningham[7] found that surface floats placed near the banks were uniformly drawn out to the thread of the stream, while subsurface floats maintained a direction sensibly parallel to the banks.

Mr. McMath[8] holds that suspended material is borne from the sides toward the center. The same statement is made by Dupuit[9] with reference to bodies floating at the surface.

M. Lagrene[10] considers the upper surface in straight sections to be sensibly horizontal so far as present knowledge reaches.

In general it may be said that the movement of surface floats shows a tendency toward the line of maximum velocity. That the difference

1 See *Annales des Ponts et Chaussées*, 1882, IV, p. 56. Also *Proceedings* of the Institution of Civil Engineers, Vol. 71, p. 66.

2 See *Proceedings* of the Institution of Civil Engineers, Vol. 71, p. 12, or *Annales des Ponts et Chaussées*, 1848, 2, pp. 28–30.

3 *Annales des Ponts et Chaussées*, 1848, 2, p. 30.

4 See "Recherches Experimentales." Darcy and Bazin. Plates XIX to XXVI. Also *Proceedings* of the Institution of Civil Engineers, Vol. 71, p. 12.

5 *Van Nostrand's Engineering Magazine*, 1879, p. 370. He claims that the cause lies in the reduction of pressure with increase of velocity.

6 "Navigation Fluviale et Maritime." V. Debauve.

7 *Proceedings* of the Institution of Civil Engineers, Vol. 71, p. 23. "Roorkee Hydraulic Experiments."

8 *Van Nostrand's Engineering Magazine*, Vol. 28, p. 35.

9 "Etudes sur le Mouvement des Eaux," p. 218.

10 "Cours de Navigation Intérieure," p. 53.

in height of surface between center and sides is a concomitant phenomenon cannot be said to be proved. There are many statements that the fact exists, but such measurements as are available fail to substantiate them.

Does Suspended Matter Move Faster Than the Current?—The question of the existence of a relative velocity between surface floats and the surface current may be said to be settled. It has been considered a source of error in the measurement of surface velocities by floats for some time past. The velocity of the float is greater than the mean velocity of the displaced water. For the same float, this relative velocity will increase with increase in depth of flotation.[1]

Major Cunningham[2] takes the contrary view, claiming that the velocity of a submerged rod is somewhat less than the mean velocity past its immersed length, so that it should only extend $\frac{94}{100}$ of the total depth to the bottom in order to give a true indication of the mean velocity in a vertical.

The experiments of M. Du Boys[3] upon the Rhone may be said to settle the matter beyond dispute. He found from experiments upon boats that they moved sensibly faster than the current, and that this relative velocity varied with the form of the boat and increased with its size and with the velocity of the current.

Experiments by M. Bérard,[4] in 1886, on an artificial canal, showed that a float moved faster than the surface velocity, but almost identically at the same rate as the mean velocity of the displaced water.

M. Du Boys,[5] however, gives the case of a boat which had a velocity of 4.46 m. in a current whose surface velocity was only 2.75 m. These differences are too great to be attributed to the fact that the maximum velocity is below the surface.

A block of wood and a floating canal-boat will not remain side by side in a river, but gradually draw away from each other, the boat taking the lead.

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[1] Noted and incorrectly explained in *Zeitschrift des Architekten- und Ingenieur- Vereins*, Hanover, 1887, p. 628.

[2] "Roorkee Hydraulic Experiments." *Proceedings* of the Institution of Civil Engineers, Vol. 71, p. 22.

[3] "La Marche des Bateaux dans les Courants Rapides." *Annales des Ponts et Chaussées*, 1886, I, pp. 199–242.

[4] "Marche des Flotteurs dans les Courants," *Annales des Ponts et Chaussées*, 1886, II, p. 830.

[5] "Hydraulique." Flamant, p. 299.

The Question of Lateral and Vertical Flow in Rivers.—Islands are said to be formed at the center of rivers at the expense of the banks, indicating a transverse flow of the particles toward the middle. Is there a regular lateral flow of the water obeying a law as fixed as that which determines the general law of translation ? If so, it will enter as an important factor in governing sedimentary movements. Prof. James Thomson[1] has demonstrated the presence of such a flow at curves where the motion at the surface is outward and at the bed is inward. This offers a suitable explanation of the cause of shoals opposite sharp bends. In a regular channel centrifugal force does not enter in to produce these effects. Are they present ? Mr. McMath says[2] that observation has failed to detect any division of a stream into ascending or descending areas other than local motions due to eddies. Major Cunningham[3] claims to have detected a surface flow toward the center in the Ganges Canal as indicated by the motion of the floats near the banks, while a sub-surface flow in the contrary sense was indirectly shown by the fact that the deeply immersed floats showed no general transverse tendency.

Experiments made by J. B. Francis[4] in regular canals with whitewash discharged through a tube opening near the bed, seemed to show a vertical movement of the water from the bed to the surface, the whitewash appearing at a distance down-stream varying from 10 to 30 times the depth. Mr. Francis offers this vertical movement as the cause of suspension of sediment.

Prof. De Volson Wood,[5] upon the ground of these observations of Mr. Francis, adopts the idea of a lateral surface movement toward the banks, with a corresponding bottom current toward the center.

F. P. Stearns, M. Am. Soc. C. E.,[6] on the other hand, holds the view that there is a motion of bottom water to the surface at the sides and toward the center at the surface.

The observations of Mr. Francis might seem to be corroborated by the positive statement[7] that the Mississippi water is constantly rising from the bed to the surface.

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1 "Encyclopedia Britannica" Article Hydrodynamics, p. 498.
2 "Silt Movement by the Mississippi," *Van Nostrand's Engineering Magazine*, Vol. XXVIII, p. 35.
3 *Proceedings* of the Institution of Civil Engineers, Vol. LXXXII, pp. 23, 24. "Roorkee Hydraulic Experiments."
4 *Transactions* of the American Society of Civil Engineers, Vol. VII, p. 109.
5 *Van Nostrand's Engineering Magazine*, Vol. XXI, 1879, p. 369.
Also *Transactions* of the American Society of Civil Engineers, June 17th, 1879.
6 *Transactions* of the American Society of Civil Engineers, Vol. XII, p. 331.
7 "Report of the Chief of Engineers, United States Army," 1883, III, p. 2218.

5. Solid Discharge of Rivers.

In many articles on river correction and in most of the treatises on river hydraulics will be found statements of the amount of silt carried by streams in various parts of the earth. The amounts are unreliable in some cases and in many are expressive of only suspended matter to the exclusion of the more or less extensive movement along the bottom. A collection of such non-homogeneous data is not deemed of value for the purposes of the present paper.[1]

Proportionate Amounts Suspended and Dragged.—The quantitative relation existing between the amounts moved at or near the bottom and those carried in free suspension has offered another opportunity for diversity of opinion.

Dupuit[2] looks upon transportation in suspension as the most important element, on the ground of the slight velocity of the materials dragged. Prof. Forshey[3] concludes that the matter pushed along the bed of the Mississippi forms about three-fourths of its total solid discharge.

M. Guérard[4] is persuaded that the greater portion of the solid matter discharged by the Rhone is pushed along its bed. The Mississippi River Commission,[5] after a series of careful measurements of sand waves at Carrollton, decided that not more than .08 of 1 per cent. of the total solid discharge was moved along the bed of the river at this point. Major Ruffner[6] states that the movement of material at the lower laminæ of the Missouri at St. Charles was believed to be as great as that in all the rest of the river. He refers[7] also to observa-

[1] The following list gives a few sources of information upon this point:

"Report on the Mississippi," Humphreys and Abbot, 1876, p. 146.

Zeitschrift des Arch.- und Ing.- Vereins, Hanover, 1867, pp. 245–50.

Proceedings of the Institution of Civil Engineers, Vol. XXI, pp. 15, 27, 459; Vol. LIII, p. 18; Vol. LI, pp. 216, 217; Vol. LVII, pp. 272–4.

The Engineer, October 25th, 1889, p. 343.

Annales des Ponts et Chaussées, 1848, II, pp. 46–48; 1860, I, p. 137; 1860, II, p. 374; 1869, I, p. 588; 1871, I, p. 15.

"Canal and River Engineering," Stevenson, p. 318.

"Improvement of Non-Tidal Rivers," Ruffner.

"Cours d'Hydraulique Agricole et Urbaine." M. Bechmann, 1895, pp. 109, 120. Also treatises on general geology.

[2] "Etudes sur les Mouvements des Eaux," p. 216.

[3] *Proceedings* of the American Association for the Advancement of Science, Nashville, 1877. See also *Van Nostrand's Engineering Magazine*, Vol. XX, p. 227.

[4] *Proceedings* of the Institution of Civil Engineers, Vol. 82, p. 309.

[5] "Report of the Chief of Engineers, United States Army," 1883, III, p. 2218.

[6] "Improvement of Non-Tidal Rivers," p. 78.

[7] The same, p. 138.

tions at Lake Providence, La., which indicated that a large amount was moving along the bed of the Mississippi at that point of which the moving sand waves represented only a small portion.

Captain Eads and Mr. Corthell[1] join with the Mississippi River Commission in the statement that nearly all the solid matter in the Mississippi is carried in suspension, while but a small proportion is dragged on the bottom.

It is believed that this last statement represents the actual case in most sedimentary rivers.

6. Tabulation of Observed Data on Dragging.

A tabulation of the best known results of experiment on velocities at at which dragging begins is given on the next page. Those given by Bouniceau appear to be taken from the results of Dubuat's and Telford's experiments. The others are believed to represent original measurements or computations. In some cases the published results do not state whether the velocity measured was that at surface, mid-depth or bottom.

Further statements of velocities are given by Weisbach, Unwin, Church, Bechmann and others, but they are all based upon the measurements detailed in this table. A limited collection of similar data is given in the Report of the Chief of Engineers, U. S. Army, 1885, I, pages 569–570.

The detail of Dubuat's and Sainjon's measurements has been given in a preceding part of this paper. The measurements in the Upper Rhine were made near Alt-Breisach, with a smooth river-bed. In the cases so marked, motion did not take place until the particles were subjected to a slight disturbance from the outside.

Login's experiments were made with a stream averaging ½ in. in depth. Telford's velocities are those at which erosion begins. Blackwell's measurements have been referred to on page 362.

The materials are given as described by the experimenter. A careful set of measurements of these velocities, made with improved apparatus, is much needed.

Displacement of Crests of Sand Waves.—For purposes of comparison, a collection has been made on page 424 of measurements on sand waves.

[1] *Transactions* of the American Society of Civil Engineers, Vol. XI, p. 262.

Table giving Velocities of Current at which Dragging Begins.

Authority	Dubuat.	Telford.	Blackwell.	Sainjon.	Login.	Rhine measurements.	Zschokke.	Verein Hütte.	Bouniceau.
Reference	Hydraulique. Paris, 1786. p. 94.	Partiot in Annales des Ponts et Ch. 1871, I, p.34.	Proc. Inst. Civil Engineers, Vol.82, pp.47-50.	Partiot in Annales des Ponts et Ch. 1871, I, p.33.	Stevenson's Canal and River Engineering, p. 315.	Zeitschrift des A. und I. Vereins zu Hannover, 1884, p. 176.	Lectures, Zürich, 1895.	Ingenieurs Taschenbuch.	"Etudes sur la Navigation," 1845, p. 19.
REMARKS.	Bottom velocity. Feet per sec.	Bottom (?) velocity. Feet per sec.	Feet per second.	Bottom velocity. Feet per sec.	Bottom velocity. Feet per sec.	Feet per second.	Feet persecond	Bottom velocity. Feet per sec.	Bottom velocity. Ft. per sec.
Soft earth		0.25							
Brick clay { allowed to settle ½ hour in water }					0.25				0.26
Potter's clay	0.27							0.26	
Soft clay		0.50						0.52	0.49
Fresh-water sand					0.667				
Large sand	0.71								0.72
Vegetable soil					0.833				
Sand		1.00							0.98
Firm sand								1 02	
Sea sand					1.103				
Gravel (size of anise seed)	0.36								0.36
Gravel (size of peas)	0.62				2.000	2.46 (if disturbed)	0.62		
Gravel (size of beans)						2.95 (if disturbed)	1.066		
Gravel (diameter, .008 ft.)				0.82					
Gravel (diameter, .03 ft.)				1.64					
Brickbat (contents, 2.59 cu.ins.)			1.75-2.00						
Gravel		2.00							
Oolites (2 39 cu. ins.)			2.00-2.25						
Slate (2.38 cu. ins.)			2.00-2.25						
Sea pebbles (1.06 ins. diameter)	2.13							2.30	2.13
Brickbats (4.76 cu. ins)			2.25-2.50						
Flints (1.96 cu. ins.)			2.50-2.75						
Brickbats (18.5 cu. ins)			2.75-3.00						
Oolites (17.68 cu. ins)			2.75-3.00						
Slate (9.06 cu. ins.)			2.75-3.00						

Flints (10.37 cu. ins.)	......	......	3.00-3.25	......	......	....	......	......	......
Pebbles	......	3.00	......	......	......	....	......	......	3.28
Boulders	......	......	......	......	......	....	......	3.08	......
Gravel (.085 ft. diameter)	......	......	......	......	......	....	3.09	......	......
Gravel (.13 ft. diameter)	......	......	......	3.28	......	....	......	......	......
Gravel (size, hazel to walnut)	......	......	......	......	......	3.48 (if disturbed)	......	......	......
Gravel (size, pigeon's egg)	......	......	......	......	......	3.67 (if disturbed)	......	......	......
Smallest gravel	......	......	......	......	......	3.87	......	......	......
Gravel (walnut size)	......	......	......	......	......	4.92	......	......	......
Gravel (.17 ft. diameter)	......	......	......	......	......	....	5.15	......	......
Gravel (weight, 2 0 grams)	......	......	......	......	......	4.92 (if disturbed)	......	......	......
Broken stone	......	4.00	......	......	......	....	......	......	3.94
Gravel (weight, 2 500 grams)	......	......	......	......	......	5.90 (if disturbed)	......	......	......
Conglomerate (soft schist)	......	5.00	......	......	......	....	......	4.90	5.00
Gravel (.33 ft. diameter)	......	......	......	4.92	......	....	......	......	......
Laminated rock	......	6.00	......	......	......	....	......	6.00	6.00
Gravel (.56 ft. diameter)	......	......	......	6.56	......	....	......	......	......
All gravel	......	......	......	......	......	6.56 (if disturbed)	......	......	......
Gravel (.18 cu. ft.)	......	......	......	......	......	....	7.22	......	......
Gravel (1.25 ft. diameter)	......	......	......	9.84	......	....	......	......	......
Hard rock	......	10.00	......	......	......	....	......	10.36	9.84
Gravel (1 09 cu. ft.)	......	......	......	......	......	....	10.29	......	......
Gravel (2.20 ft. diameter)	......	......	......	13.12	......	....	......	......	......
Gravel (2.18 cu. ft.)	......	......	......	......	......	....	15.44	......	......

Tabulated Data on Movement of Sand Waves.

Locality.	Date.	Observer.	Velocity of Stream. Feet per Second.			Average depth of stream. Feet.	Material.	Dimensions of Wave. Feet.		Velocity of crest. Feet per day.	Reference.
			Surface.	Mean.	Bottom.			Height.	Length.		
Mississippi, at Helena	March to June, 1879.	J. B. Johnson		3.58		13 to 30	Sand.	5.0	328.0	17.75	Rep't Chf. of Engrs., U. S. A., 1879, p. 1967.
Loire, at Angers	June to Nov., 1858.					Scale read from − 0.3 to + 0.85.	Sand.			7.35	Debauve Nav. Fluviale, p. 135.
Loire, at Angers	Nov., 1858, to June, 1859.					Scale read from + 0.80 to + 3.75.	Sand.			29.52	
Mississippi, at Lake Providence	Nov., 1879, to Nov., 1880.	Hider				(High water) 76.	Sand.	13.0	470	22.5	Rept. of Chf. of Engrs., U. S. A., 1883, pp. 2197–98, Appendix S. S.
"	"	"				(25 ft. below high water) 46.	"	6.6	252	9.7	
"	"	"				(High water) 80 to 100.	"	6.9	332	42.	
"	"	"				(25 ft. below high water).	"	7.6	325	10.8	
Sacramento, at Kerscheval's	March, 1879	Le Conte	5.50		4.48 (2 to 7 ft. above bottom).	20 to 25 ft.	Sand.	2	13		Report of Chf. of Engrs., 1879, p. 1759.
Garonne, at Col-de-Fer	1840–43	Baumgarten		6.5 to 8.0			Gravel.	4.2		82 (ft. per year).	Annales des Ponts et Chaussées, 1848, 2.
Loire	1858–59	Partiot					Sand.			36.0	Sables de la Loire. Partiot. Annales I, 1871.
"	"	"					"			16.4	
"	"	"					"			16.4	
"	"	"					"			6.55	
Loire, at Nantes	1858	Duval					Sand.			4.2	Partiot. Annales des Ponts et Chaussées, 1871, I, p. 43.
"	"	"					"			11.2	

Additional measurements, made by M. Sainjon, are given at page 371 of this paper.

In general, it may be said that the displacement of these wave crests increases with the stage and with the velocity, at least up to a certain point of bottom velocity. Their form and motion is most regular at times when the river is neither rising nor falling. Their motion is most rapid when the river is rising. They are largest in deep water.

7. Velocities of Vertical Current Required to Keep Particles Suspended.

A particle whose specific gravity is greater than 1 will sink in quiescent water when viscosity is overcome. It will, when falling freely from rest, after a very short period of acceleration, attain a state of velocity practically uniform. The same particle should be kept suspended indefinitely by a constant current, whose vertical component has a velocity equal to that asymptotically approached by the falling particle.

Experiments have been made to determine the velocities of currents necessary to keep particles of various sizes and specific gravities suspended when acting in a direction opposed to gravity.

The table[1] on page 426 gives the results of experiments made by M. Thoulet. It represents the maximum velocities in millimeters per second of, and the thrusts in milligrams exercised by, currents capable of holding suspended, at a fixed point in a tube, spherical grains of radius varying from 0.1 to 2.5 mm., and of densities, in air, between 1.5 and 4.0. The velocities are taken from diagrams constructed from results of actual experiment. The thrusts P are computed on the supposition that a current with a velocity v, in millimeters, which holds in suspension a body of density γ', exercises against the body a thrust

$$P = \frac{4}{3} \pi r^3 (\gamma' - 1)$$ (in milligrams, where r is expressed in millimeters).

The range of values for (r) and (γ') is sufficient to cover all ordinary mineral grains.

There can be little doubt that the velocity of vertical current or the amount of vertical thrust required for the suspension of ordinary grains is very slight. Col. Mansfield reports[2] observations on grains of sand allowed to fall from rest in water. The maximum velocity

[1] For further details see p. 383; also *Annales des Mines*, 1884, 1, p. 521.

[2] "Report of Chief of Engineers, United States Army," 1886, pp. 1298–1299.

Radius (r) of grains in millimeters.	VELOCITY (v) OF THE CURRENT IN MILLIMETERS PER SECOND. THRUST (P) IN MILLIGRAMS EXERCISED AGAINST THE SPHERICAL GRAIN OF DENSITY (γ').											
	$\gamma' = 1.5$ v	P	$\gamma' = 2.0$ v	P	$\gamma' = 2.5$ v	P	$\gamma' = 3.0$ v	P	$\gamma' = 3.5$ v	P	$\gamma' = 4.0$ v	P
0.1.......	13	0.0002	23	0.004	32	0.006	40	0.008	47	0.01	53	0.01
0.2.......	23	0.002	40	0.03	55	0.05	69	0.07	79	0.08	85	0.10
0.3.......	32	0.006	57	0.11	78	0.17	94	0.23	106	0.28	116	0.34
0.4.......	40	0.01	70	0.27	94	0.40	114	0.54	129	0.67	143	0.80
0.5.......	51	0.03	82	0.52	107	0.78	132	1.05	151	1.31	168	1.56
0.6.......	57	0.04	92	0.90	120	1.35	147	1.81	168	2.26	187	2.72
0.7.......	61	0.07	100	1.44	133	2.15	163	2.87	185	3.59	205	4.30
0.8.......	65	0.11	108	2.14	142	3.22	174	4.29	198	5.36	221	6.44
0.9.......	68	0.15	116	3.05	152	4.58	185	6.11	211	7.63	237	9.16
1.0.......	72	0.21	123	4.19	161	6.28	195	8.38	224	10.47	252	12.56
1.1.......	75	0.28	128	5.57	169	8.36	203	11.15	234	13.94	264	16.72
1.2.......	78	0.36	133	7.24	175	10.86	211	14.48	243	18.10	273	21.72
1.3.......	80	0.46	137	9.20	180	13.80	218	18.40	252	23.01	281	27.60
1.4.......	82	0.57	141	11.49	184	17.24	224	22.99	260	28.73	288	34.48
1.5.......	84	0.71	144	14.13	188	21.21	229	28.27	267	35.34	295	42.42
1.6.......	86	0.86	147	17.15	192	25.74	234	34.31	271	42.89	300	51.48
1.7.......	88	1.03	149	20.57	195	30.87	237	41.16	274	51.45	304	61.74
1.8.......	90	1.22	151	24.42	197	36.64	240	48.86	277	61.07	308	73.28
1.9.......	92	1.44	153	28.72	199	43.10	243	57.46	280	71.83	312	86.20
2.0.......	94	1.67	154	33.50	201	50.27	246	67.02	283	83.78	315	100.54
2.1.......	95	1.94	155	38.78	202	58.19	249	77.58	286	96.98	317	116.38
2.2.......	96	2.23	156	44.59	203	66.90	251	89.20	288	111.50	319	133.80
2.3.......	97	2.55	156	50.95	204	76.45	253	101.93	290	127.41	321	152.90
2.4.......	98	2.89	156	57.89	205	86.86	254	115.81	291	144.76	323	173.72
2.5.......	98	3.27	156	65.44	206	98.17	255	130.90	292	163.62	324	196.35

reached at the bottom showed that a vertical current of 1 or 2 ins. per second would keep them suspended.

Mr. T. E. Login,[1] found that the following materials had a rate of sinking in water of, and consequently would be sustained by a vertical current of, a velocity equal to the numbers given below:

Materials.	Velocity required. (Feet per second.)
Brick clay (mixed with water and allowed half hour to settle)	0.009
Fresh water sand	0.166
Sea sand	0.196
Rounded pebbles (size of peas)	1.000

Diagrams have been prepared by Richards[2] and Woodward to show the relations existing between the specific gravity, diameter and velocity of fall in water of various minerals. They are constructed from a formula given by Rittinger.[3]

$$V = 2.44 \sqrt{D(\delta - 1)}$$

where V = velocity of fall in millimeters per second.

D = diameter of particles in meters.

δ = specific gravity of the mineral.

These diagrams are extended to cover specific gravities between 1 and 15, diameters between 0 and 0.06 m., and velocities of fall up to 2.3 m. per second.

8. Results Expressed in the Form of a Series of Propositions.

The following propositions are believed to express the main facts, so far as they are known at present, which must be recognized by any broad theory of the cause of the suspension of sediment:

1. The movement of solids by water currents may take place by dragging, by intermittent suspension or by continuous suspension.

2. Motion in each of the three ways is increased with increase of depth; yet the depth itself can only affect the intermittent motion.

3. Motion by each of the three ways is increased by increase in mean velocity.

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[1] *Proceedings* of the Royal Society of Edinburgh, Vol. III, p. 475. Also "Canal and River Engineering," Stevenson, p. 315.

[2] "The Velocity of Bodies of Different Specific Gravity Falling in Water." Richards and Woodward. *Transactions* of the American Institute of Mining Engineers, 1890, Vol. 18, pp. 644–648.

[3] Rittinger's "Aufbereitungskunde," 1867, p. 195..

4. The presence of sediment in a stream decreases its mean velocity.

5. Dragging as well as suspending power increases with the heaviness of the liquid and with its coefficient of viscosity.

6. By far the greater amount of solid material transported by sedimentary rivers is carried in continuous suspension.

7. Sand waves of considerable size are formed in the larger rivers. Their motion down stream is slow, increasing in rate up to a certain critical value of bottom velocity and then decreasing with further increase.

8. The fineness of material in suspension increases from the rise to the embouchure of rivers.

9. The weight of suspended material per cubic unit of water decreases from rise to embouchure.

10. Increase in vortex motion increases power of transport.

11. Continuous vertical or lateral currents which could not be explained by local causes in rivers have not yet been proved.

12. The phenomenon of suspension requires for its explanation a continuous upward force. Intermittent forces are not sufficient, although the intensity of the force may vary.

13. Bodies suspended in flowing water, either intermittently or continuously, tend to acquire a velocity greater than that of the water surrounding them.

14. The transportation of material consumes part of the energy of any silt-bearing stream. A greater load of fine particles than of coarse can be carried with the same expenditure of energy.

Part III.—Discussion of Theories of Suspension.

The explanations offered as to the cause of this phenomenon, as detailed in the preceding pages, fall naturally into four categories. It will be well to examine each in the light of the facts at hand before drawing conclusions as to their relative value.

(*a*) *Theory of a Continuous Upward Flow.*—J. B. Francis[1] Past-President Am. Soc. C. E., sought to explain the suspension of sediment in streams by the presence of a continuous upward flow of the water at the bed. This flow was believed to be proved by experiments made by liberating whitewash at the bed of two different channels and noting its appearance at the surface at distances down-

[1] *Transactions* of the American Society of Civil Engineers, May and June, 1878.

stream varying from 10 to 30 times the depth. The experiments of M. Thoulet[1] have shown how slight an upward current is required to produce this effect. Were such a resultant upward current proved, it might offer a satisfactory explanation of the phenomenon. There are, however, certain objections to this view which seem to render it inadmissible. Considering a long stretch of river, a steady flow from bed to surface at the center must be accompanied by a corresponding flow outward to the sides and a downward reverse flow along the bed from the sides to the center. Such a flow has not been observed. On the contrary several writers[2] have advanced the idea of a flow in the contrary sense, though this, too, must be regarded as yet unproved.

Again, even were the flow from bed to surface at center and outward to the sides proved, it would constitute no explanation of continuous suspension, unless the velocities of flow at center and sides were unequal, since it would give no resultant upward thrust. The algebraic sum of the vertical components of all the internal movements of the liquid should reduce to zero in the stretch considered.

Proofs of flow from bed to surface or from sides to center based upon indications offered by floating substances—the case in both Mr. Francis' and Major Cunningham's experiments—can not be considered conclusive. In the one case the movement might be attributed to local currents induced by the presence of the experimental apparatus. In both cases, the fact that a floating body tends to move faster than the surrounding medium and would follow the line of least resistance would cause floating substances to indicate currents which did not actually exist. This matter will be referred to later.

(*b*) *Discontinuous Upward Flow or Eddy Theory.*—There are certain writers who attribute the entire suspending power of streams to vertical currents incident to the complex eddying motion induced by the asperities of the bed. The numerous valuable articles[3] by R. E. McMath, M. Am. Soc. C. E., have taken the strongest position on

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[1] See p. 383.

[2] See *Proceedings* of the Institution of Civil Engineers, Vol. 71, p. 23 and discussion. Also *Transactions* American Society of Civil Engineers, Vol. 12, p. 333.

[3] "Silt Movement by the Mississippi." *Van Nostrand's Engineering Magazine*, Vol. 28, 1883, p. 32.

"The Mississippi as a Silt Bearer." *Van Nostrand's Engineering Magazine*, Vol. 20, 1879, p. 218.

"Theory and application of the Permeable System of Works for the Improvement of Silt-Bearing Rivers." *Engineering News*, November 1st, 1879.

this line. Upon the basis that the fact of suspension itself is an evidence of a resultant upward thrust, Mr. McMath states his position in these words:[1]

"This third hypothesis goes but one step farther in ascribing to the irregular movements the whole work of suspension upon the ground that a cause known to exist wherever the fact to be accounted for occurs, and admitted to be efficient, must be considered the sole cause unless a co-working agency is known, or the cause is insufficient to produce the observed result. Observation readily detects whirls, boils and eddies in the act of bringing water and suspended material from the bottom to the surface and laterally from the sides to the center of the river. Observation has never detected any other cause incident to the flow of streams which produced these effects."[2]

The efficiency of vortices in producing local results has passed beyond the range of controversy. M. Boussinesq[3] divides them into two classes; first, those in which the constituent water is constantly changing as the result of an axial flow which increases in velocity as the radius of curvature decreases; second, those in which the constituent water remains the same, being formed during an interval of time by a definite mass of fluid and manifesting themselves in a complex rotation.

A case of the first kind is the common vortex over the discharge pipe of a hand basin. One of the second is seen in the experiment of the revolving glass or basin of water described earlier in this paper in the experiments of M. Fargue and M. Gallois.

In both forms of vortex the tangential velocity increases with approach to the axis in contradistinction to the case of a rotating solid. In each case solid material obeys an impulse toward the axis whether there be a flow of liquid in that direction or not. This is due to the tendency of the solid to move faster than the liquid and in so doing to follow the line of least resistance, *i. e.*, the line where differences of velocity are least. In the first form an additional impulse toward the axis is received from the current setting in that direction. These phenomena are clearly shown in the experiments referred to, though

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[1] "Silt Movement by the Mississippi." *Van Nostrand's Engineering Magazine*, Vol. 28, p. 35.

[2] "The suspension of matter involves an upward motion of the water or medium in which such matter is suspended, if in no other way, by the law of adhesion. * * * Upward motion of the suspending medium involves of necessity a downward movement of equal volume, but not necessarily of equal velocity." McMath in *Engineering News*, November 1st, 1879.

[3] "Essai sur la Théorie des Eaux Courantes," p. 616.

M. Gallois'[1] explanation is at variance with that given above. He takes the position that the particles are impelled toward the center because the relative velocities are greatest at that point. This is incompatible with the theory that the standard form of a vertical velocity curve in streams is a parabola. If the friction initiated at the sides exercises its retarding effect progressively toward the center, as is believed to be the case in rivers, the absolute velocity near the axis of the vortex should be greater, but the relative velocities of the fluid filaments should be a maximum near the sides. In other words the solids would move toward the axis of the vortex with radial velocities varying directly with the distance from the axis. According to M. Gallois' explanation this relation would be an inverse one.

In a flowing stream these eddying movements are present in the forms described and in numerous intermediate states. Irregularities in the bottom sometimes send currents to the surface in the form of boils where there appears to be only a swift vertical velocity without much rotation. In the complex motion of the stream these visible disturbances are but the type of an infinite variety of similar movements taking place between small groups of molecules. These are not so evident to the eye, but consume in the aggregate a large proportion of the stream's energy. The asperities of the bed and banks send off these rotary groups with axes inclined at all angles and with velocities of translation having a resultant in the stream direction. Whatever resistance is offered along the air profile will manifest itself in complicating the direction of these movements of translation. The vital question is to know the direction of the resultant motion. Has it a component acting upward ?

It is seen at once that vertical motion of the water itself can only be a local phenomenon. The resultant of all the external forces acting upon a given stretch of river will have a direction down stream, and will approach zero as the motion approaches uniformity. Its vertical component will be downward, not upward. The same thing will be true of all the complex motions in the interior of the liquid prism considered in the aggregate. It is true, however, that the reverse downward current need not equal in velocity the original upward one.[2] The diminution in velocity may be counterbalanced

[1] See *Engineering News*, March 23d, 1893.

[2] This fact is noted, without comment, by Mr. McMath in *Engineering News*, November 1st, 1879. It is thought that he was the first to suggest it in connection with suspension.

by an increase in the moving area. This is an important point affecting the power of suspension. While there is no resultant vertical motion of the water, there is a resultant vertical thrust exercised upon sediment in the aggregate and acting as an efficient cause of suspension.

The thrust exercised by a current upon an immersed solid is

$$P = k\ F\ \gamma\ \frac{v^2}{2g}$$

and obviously varies with the square of the velocity. An eddy, having an upward component of velocity represented by 4, would exert an upward thrust, available for suspension, proportional to 16. In descending, the same water might cover twice the area, and have a downward velocity of 2. Then the corresponding downward thrust would be proportional to 8. The resultant of such a local system would be an upward thrust available for continuous suspension. In addition to this, particles carried by the vortex to the surface, and especially when freed at that point from its influence, would exhibit the phenomenon of temporary suspension, before gravity had again brought them back to the river bed. Cover the stream with systems of this character, and there results a modified form of what is actually seen. Eddies are induced by the rugosities met with in the earth and air profiles. The abrupt changes in the bottom, and its relatively unyielding character, cause the upward currents to have the greater velocity in general, though they must of necessity be restricted in relative extent.

The fact that the descending areas must be much greater than the ascending ones in order to give rise to this force shows that, in the major part of the stream, an active force is at work tending to carry material to the bottom, aside from the force of gravity acting upon the particles. This suggests, though it does not prove, the existence of another cause of suspension, and such a cause is actually found, as shown later.

Here, then, in obedience to the law which governs the thrust exercised by water impinging upon a solid, there is a resultant force acting upward in flowing streams, and capable of performing an efficient part in the continuous suspension of solid matter. While the aggregate of all the interior motions of the fluid can have no upward resultant, still the thrusts exercised upon solid suspended matter by these motions can and do have such a resultant as shown.

It is evident that this force would disappear in circular conduits, flowing full, since a uniform profile may be assumed. The eddies would be thrown off with like intensity at all points toward the center.

M. Boussinesq[1] attributes increase in vortical motion at the walls to any one of these causes; increased mean local velocity, increased roughness of lining or increase in hydraulic mean radius. The effect of the first two causes is evident. The influence of the increase of area per unit of wetted perimeter is thought to be shown by the greater field of action allowed for oscillatory movements perpendicular to the walls. These vibrations help in detaching groups of molecules and cause such groups to suffer sudden changes in intensity of tangential friction at the walls which, in turn, favors their formation into vortices.

In a circular conduit running full this would indicate an increase in vortical movements at the walls with increase in diameter. In passing from the walls to the center of the current, M. Boussinesq thinks the vortical agitation should increase where the wetted perimeter is concave, as in the case of closed conduits of rectangular or rounded forms, running full, because the field of action for each vortex is constantly narrowing and interference increases. On the other hand, this agitation should be less and be practically uniform for a rectangular cross-section of indefinite length of base. The agitation should be of about the same intensity in a large circular or rectangular conduit running full as when running half full. The action of the free surface in reflecting these movements ought not to differ widely from the action of the upper half of the section upon the lower half when running full.

Considered as a whole, the vortex theory,[2] as advocated by Mr. McMath, is entitled to a position as one of the major causes of suspension. The statement that it is the sole cause, and that observation has never detected any other cause incident to the flow of streams which has produced these effects would seem too broad a claim.

(c.) *Theory Based upon Eddies and Relative Velocities.*—Partiot was probably the first to give prominence to the suspending power of

[1] "Theorie des Eaux Courantes," p. 47.

[2] A valuable paper by William Starling, M. Am. Soc. C. E., Chief Engineer of the Mississippi Levee Commission, is in press at the present time, which brings this theory prominently forward. The term "vortex theory" is here used in a restricted sense, as indicated by the context.

eddies. He bases his explanation of suspension upon the presence, in these vortical movements, of exaggerated relative velocities which, in conjunction with the motion of the body, cause a thrust toward the most rapid filaments. The particles are then carried along with the motion of translation of the eddy.

Where eddies are not the acting force, he follows Dupuit's explanation as given hereafter.

(*d.*) *Theory Based upon Relative Velocities.*—This theory was brought forward by Dupuit. It utilizes the fact that all partially or wholly submerged bodies tend to move faster than the mean velocity of the displaced water. This makes a choice of path for relative motion necessary. The path chosen will be that which offers the least resistance, *i. e.*, diagonally toward the most rapid filaments.

Take the case of a floating homogeneous sphere. Let it have a velocity of translation in the stream direction equal to that of the mean of the displaced filaments. Assume uniform stream motion. Place it near the left-hand shore. The filaments of water at the right of the body are moving faster than its center of gravity, and by their friction tend to revolve it in an anti-clockwise direction. On the opposite side of the ball the friction is reversed in direction, and aids in producing the same rotation. What is the result upon transverse motion?

The ball will tend to place its center of gravity in the line of the resultant resistance of the filaments ahead of it. But in the theoretical case considered there is no resultant resistance upon the sphere, since it moves with the same mean velocity as the displaced water. The law stated above, then, does not call for any transverse motion under the conditions named.

Introduce the fact that the body has a velocity greater than that of the mean of the displaced filaments. A new element is introduced, for there is now a resultant resistance from the filaments ahead which is proportioned to the square of the relative velocity. This relative velocity, and consequently the resistance, increases until the resistance is equal to the accelerating force, when the motion becomes uniform. It is now incumbent upon the body to choose a path relatively to the fluid. It will tend to place its center of gravity in the line of action of the resultant resistance. This line of action is to the right of the center of gravity of the body. It will then take a diagonal path to the right, or toward the most rapid filaments.

The line of application of the mean resistance will coincide with the line of action of the mean velocity of the water immediately ahead. At any point of its path the mean resistance offered will be least, *i. e.*, the velocity of the body will be most nearly equal to the mean velocity ahead, if the center of the body is in the line of action of this mean velocity.

In summing up, then, Dupuit's theory of suspension rests upon the fact that submerged bodies tend to move faster than the mean velocity of the displaced water, and in so doing choose the line of least resistance.

It is the only satisfactory explanation yet offered of the phenomena shown in the experiments with rotating vessels, which are described by M. Fargue and M. Gallois. It offers an explanation of the increase in suspending power, with increase in depth and velocity. In the "Report on the Mississippi River" by Humphreys and Abbot (page 254) it is shown that the parameter of the horizontal parabola of velocities 5 ft. below the surface, at any stage, is proportional to the square root of the corresponding mean velocity. The same should be true of the vertical curve.

The reasonableness and value of this theory seem evident. Its incompleteness as an explanation of the whole phenomenon is shown by the fact that it takes no account of the suspending power of eddies and offers no explanation of the presence of sediment above the line of maximum velocity.

Before stating the conclusions to which this analysis of theories leads, it will be well to place emphasis upon a cause of suspension which has only been indicated in a general way.

Dupuit[1] suggested that the resultant of all the pressures upon a submerged body was greater in flowing or agitated than in quiescent water. He explains it on the ground of relative velocities of the filaments as detailed above.

M. Flamant[2] has adopted the same idea as an explanation of the tendency of surface floats to move faster than the current. His argument is that the floating body weighs more in agitated water than the weight of the water displaced, and that the excess shows its presence in the increased velocity. The explanation implied is that there is a resultant upward thrust in the surrounding fluid due to its agitation.

[1] "Etudes sur Le Mouvement des Eaux," 1848, p. 217.
[2] "Hydraulique," 1891, p. 298.

The explanation offered by Du Boys[1] for the increased velocity of surface floats has indicated the presence of a forward thrust, but has not called attention to the fact that this thrust has a direction above the horizontal. This follows from the discussion under (*b*) preceding. Experimental demonstration is wanting, but the fact that continuous suspension exists above the line of maximum velocity is an evidence that Nature shows the phenomenon indicated by theory.

It should be remembered that the line of maximum velocity has often been found at the surface. In such cases the suspending power due to the body's excess of velocity and tendency toward the line of least resistance acts from bed to surface in conjunction with the upward thrust due to the eddies. In the majority of cases it is found below the surface, and here a force must be acting downward to assist gravity in opposing suspension above the line of maximum velocity. This would indicate for such cases a decrease in suspended matter near the surface. The burden of the work then falls upon the upward thrust of the vortices. The fact that agitation increases from the line of maximum velocity to the surface tends to make the effect of this downward thrust disappear, since the latter decreases in intensity toward the vertex of the vertical curve. In this way marked differences in the intensity of sediment charge at the surface and at the line of maximum velocity are prevented. A difference in the amount carried at the surface ought to be shown according as the vertex of the curve of vertical velocities is raised or lowered—for instance, by the wind. The surface quantities should be greater when the maximum velocity is at the surface.

Conclusions.

It is believed that the suspension of sediment in flowing water may be attributed to three causes:

First.—The resultant upward thrust due to eddies, conditioned upon the facts that the earth profile offers more rugosities than the air profile and the effort exerted by a current upon a solid varies as the square of the relative velocity.

Second.—The resultant upward motion of solids due to the fact that an immersed body tends to move faster than the mean velocity of the

[1] "Sur la Marche des Bateaux," *Annales des Ponts et Chaussées*, January, 1886, pp. 199–242.

displaced water and in such motion tends to follow the line of least resistance.

Third.—The viscosity of the water.

All of these causes will be present in every stream flowing under natural conditions. The first two causes will alternate in efficiency with the complex motion of the stream. At certain points of the vertical curves of velocities the second cause may entirely disappear as the curve becomes irregular, but such conditions are abnormal.

Experimental research is needed for further progress along these lines. Some of the more important questions awaiting investigation will be indicated.

Can it be shown experimentally that the power of suspension in flowing water increases with the increase of relative velocities in the vertical?

Can a measurable difference in volume of displacement be detected for the same body in quiescent and in flowing water?

What is the normal form of the vertical and horizontal sediment curve?

Can it be shown by experiment that suspending power increases with depth, the mean velocity remaining unchanged?

What is the influence of a contraction in width upon the form of the vertical curves of velocity and sediment?

What is the form of the vertical curve of velocities corresponding to incipient dragging for stream beds composed of the range of materials usually found in practice?

Can it be shown by experiment[1] that a heavier load of fine than of coarse particles can be carried with the same expenditure of stream energy?

What is the effect of temperature upon viscosity and mechanical suspension?

An apparatus has been designed for the purpose of studying the first of these questions. It consists of a long, narrow trough, fitted with glass sides for nearly its whole length, which is joined to a wooden receiving reservoir. A steady flow is set up from the reservoir through the experimental channel.

Two submerged jets, each covering the entire width of the channel,

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[1] A general method of experiment has been indicated by Ashbel Welsh, Past-President Am. Soc. C. E., *Transactions*, American Society of Civil Engineers, Vol. xi, p. 162.

are introduced near the reservoir through suitable copper guides, arranged so as to create the minimum amount of agitation in the jets and in the steady flow progressing independently.

These jets discharge under a head of 40 ft. One is placed near the bed, another near the surface of the channel. The object sought in the design was to obtain a means of controlling the form of the vertical velocity curves by varying the discharge from each of the jets. This is controlled by stop-cocks. The velocities at different parts of the vertical are measured by a cluster of Pitot's tubes.

The experiments have not yet been made. Preliminary trials have shown, however, that the control of the curve of velocities is appreciable for a sufficient distance from the jets to afford ample field for experimentation.

The author takes pleasure in expressing his deep sense of obligation to Prof. E. A. Fuertes for constant assistance and suggestions, and to Prof. I. P. Church for kindly criticism, which has led to modifications in some of the views expressed. This opportunity is gladly taken to mention the kindness of M. Edouard Collignon, Inspecteur Général des Ponts et Chaussées, in affording, among other courtesies, unusual library privileges at the École Nationale des Ponts et Chaussées, Paris; and of Prof. Conrad Zschokke, of Zurich, in assistance rendered in various ways. He wishes, also, to express his appreciation of the continued courtesy shown him by M. Cordier, the librarian of the Ecole des Ponts et Chaussées at Paris, and by Prof. Rudio, the librarian of the Zurich Polytechnikum, during his use of those libraries.

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PAPERS.

THE NEW WATER-WORKS OF HAVANA, CUBA.

BY E. SHERMAN GOULD, M. AM. SOC. C. E.

TO BE PRESENTED SEPTEMBER 16TH, 1896.

The first attempt to supply the city of Havana with water was made in 1835, by the construction of the "Aqueducto Fernando Sétimo," which introduced the water of the Almendares River for public use. This supply was very inadequate. The water was diverted at a point about 4½ miles from the city, and, after passing through a rude and defective filter, was brought into the city in an 18-in. cast-iron pipe. This supply only amounted to about 1 333 000 galls. per 24 hours, and was liable to become very turbid from surface wash, the clarifying effect of the rude filtration being of slight account.

In order to obtain a better and more abundant supply, it was decided to collect in a suitable basin, a large number of springs which were found in the neighborhood of Vento, situated upon the River Almendares, about 10 miles from Havana. This idea seems to have originated with General Concha, and its execution was entrusted to

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

General Francisco Albear, who at the time was President of the Board of Public Works of Cuba, and to whose genius and ability the credit of getting the project into practical shape is wholly due.

This new project was inaugurated November 28th, 1858, and in February, 1859, General Albear took charge of the work. The two following years were spent in surveys, examinations, collecting materials and other necessary preliminaries.

The springs, some 400 in number, giving a calculated yield of about 40 000 000 galls. per 24 hours, were collected in a large masonry-lined basin, with suitable overflows and sluices. These springs are situated near the river, on the farther bank from the city, and a high retaining wall forming one side of the basin prevents the entrance of the water of the river when it is swelled by freshets. A tunnel was constructed under the river, in which two lines of cast-iron pipe 1 m. in diameter were laid. These pipes connect with a masonry aqueduct about 6 miles long leading to the distributing reservoir at Palatino. This aqueduct is oval in section, about 8 ft. high and 6.5 ft. in maximum width, with a total sectional area of $41\frac{1}{4}$ sq. ft., and an area below the spring line of the arch of $24\frac{1}{3}$ sq. ft. The slope is $\frac{1}{5000}$, and the estimated velocity, when running to the level of the spring line, 2.43 ft. per second, delivering 59 cu. ft. per second, or about 38 000 000 galls. per 24 hours.

The first stone in the main wall of the collecting basin was laid June 26th, 1861. The first stone of the tunnel was laid in May, 1865. The water first ran through the pipes laid in the tunnel March 1st, 1872. The circumstances which brought about this slow progress are too numerous, complicated and uncertain to be entered into here. As it would evidently have been unwise to delay the delivery of at least a part of the water until the completion of the work, it was determined to connect that portion of the aqueduct already built with the old distribution. Accordingly, in June, 1872, the aqueduct was connected with the filter beds, already mentioned, and a partial supply of water, of improved quality, was thus obtained.

The total actual cost of the works executed up to the death of General Albear in October, 1887, according to his official statements, was under \$3 500 000. These works included the receiving basin, tunnel and aqueduct. Of the thirty years which intervened between the commencement of the work in 1859 and its resumption in 1889,

about to be described, there were only ten in which actual work was done, owing to want of funds and political disturbances.

Meanwhile the project of the new water supply had attracted the attention of American capitalists. The late Daniel Runkle, then President of the Warren Foundry and Machine Co., studied the project carefully, aided by the late J. C. Campbell, M. Am. Soc. C. E., then Chief Engineer of the Croton Aqueduct, who visited Cuba for the purpose, with the result that, in November, 1889, a contract for the completion of the works, including the building of the Palatino distributing reservoir and piping the city, was awarded to Messrs. Runkle, Smith & Co., of New York, who were represented in Havana by Mr. Richard Narganes, the president of the advisory board in Havana being the Marquis of Pinar del Rio.

The new works were inaugurated January 31st, 1890. The author, after a preliminary visit to Havana to report upon the project, was engaged by Messrs. Runkle, Smith & Co. as their engineer for the execution of this contract. He reached Havana in February, 1890, and preparations were at once commenced for work.

The contract for the entire work, including furnishing and laying the pipe, and building the reservoir, was taken at the engineer's estimate. The system of estimating public works in Cuba is somewhat peculiar. The plans having been prepared, an estimate is made of the exact quantities of each class of work required, down to the minutest detail. The plans, quantities and estimates, accompanied with a report, are then forwarded to the home government, in Spain, and if approved are forwarded back and can be acted upon. After such approval, it is extremely difficult to have any changes made, anything radical involving first acceptation by the proper authorities in Cuba, and then submission to the home authorities, and a royal order for the change. A feature which is frequently embarrassing is that the quantities and cost of each class of work must stand by themselves. If, in the execution of the work, the quantity, and consequently cost, of one class should fall short of that estimated, the surplus would not be available for making up the deficit in any other class which might overrun the estimate. Hence, the anomalous circumstance might occur, of being obliged to ask for a new appropriation for extra work, while there was still an unexpended and unexpendable balance on hand. The full set of documents of such a project comprise *planos*, *mediciones*, *presupu-*

esto and *memoria*. The *planos* are the general drawings, illustrating the entire project, but only in a general way; the *mediciones*, or measurements and quantities, must be given, if expressible in cubic measurements, by the number of similar pieces of work, with their common length, breadth and thickness, which factors, multiplied together, give the total cubication. It will be readily perceived how inconvenient this rule is when dealing with pieces of masonry of irregular shape. In such cases the actual cubication must be first calculated, and then the amount divided up in such a way as to be expressible under the three dimensions of length, breadth and thickness.

There is another singular rule regarding the execution of public works in Cuba, which it is believed holds good in Spain also, which is, that implicit conformity to all plans and instructions given by the chief engineer does not relieve the contractor from the responsibility of failure, should it ensue, unless before commencing the work he files a written protest. In other words, his acceptance of a contract after examination of the plans and documents is held to be an approval of the design, which then virtually becomes his own, and for the success of which he, and not the engineer, is responsible. The want of reasonable foundation for this extraordinary regulation made it impossible for the author to believe in its existence until it was affirmed to him by unimpeachable authority.

The work to be done under the contract contemplated, besides the furnishing and laying of the pipe, the building of the distributing reservoir already mentioned. This reservoir is about 4 miles from the city. It is almost wholly in excavation, and consists of two compartments, or tanks, each containing about 8 000 000 galls. The bottom is covered with a concrete floor, and the sides are formed of rubble masonry retaining walls. From outside to outside of foundations of both tanks the area covered is 245 x 500 ft., or about 2.8 acres. The elevation of the bottom above city datum (which is understood to be mean low water) is 95.57 ft. The elevation of the lip of the overflows is 114.83 ft. The height of the retaining walls, from the level of the concrete floor to the top of the wall, is 20.5 ft. The top thickness of the wall is 2.79 ft.; its bottom thickness, not counting a small off-set, 6.73 ft. The face has a batter of 1 in 10, and the back is built in offsets. The area of cross-section is 97.20 sq. ft.

Water is admitted to this reservoir from the aqueduct through an influent gate chamber. It may be admitted into either side of the reservoir, or both sides at once; or it may be shut off from either or both, and run through a masonry culvert in the center wall directly into the effluent gate chamber. The water may be also entirely shut off from the reservoir and gate chamber and turned into a waste culvert passing around the reservoir. Each side of the reservoir has an overflow discharging into the culvert, and there is another overflow in the aqueduct just before entering into the influent gate chamber. All the above operations are effected by sluice gates.

The effluent gate chamber contains a number of openings controlled by sluice gates, of which there are twelve in all used at the reservoir. From these openings the water enters a collecting pipe 42 ins. in diameter, running parallel to the side of the reservoir. Out of this pipe run the various other pipes destined for the distribution of the water to different parts of the city. These pipes, as well as the collector, are governed by valves. This part of the work will be referred to again. For the present it will suffice to say that the working of the system was perfectly satisfactory, although compared with the means usually employed in the United States to accomplish the same purpose, it appears unnecessarily complicated.

The original project contemplated a covered reservoir, which would seem to be especially proper in a tropical climate. The general drawings showed a series of granite columns, spaced 20 ft. apart from center to center, supporting a roof of concrete in the shape of groined elliptical arches, the concrete at the crown of the arches being about 1 ft. thick. The granite pillars were to consist, above the base block, of three stones each, respectively 7.38 ft. high by 2.63 ft. square, 6.56 ft. high by 2.30 ft. square, and 5.58 ft. high by 1.97 ft. square. These separate blocks were to be superposed, one upon the other, joined only by a bed of mortar, and were to be surmounted by a granite capital, forming a skewback whence the groined arches were to spring.

The great difficulties attending the execution of this design were apparent at first sight, and an endeavor was at once made to substitute a simpler and more common method for covering the reservoir. Several plans were submitted, with estimates showing their greater economy, safety, ease and rapidity of execution, the merit of which, as compared with the original design, was recognized by the highest

authorities, both in Havana and Madrid, but they met with great opposition from the city officials, and, finally, after prolonged discussions, the question was left an open one as to whether there should be any cover built at all. There the question still remains to this day.

The amount of money called for by the estimates was furnished by the Spanish Bank of the Island of Cuba, and was paid to the contractors in monthly installments as the work progressed, the estimates being signed by the engineer-director of the works, and the engineer-inspector appointed by the bank. The director of the works was Major Joaquin Ruiz, and the inspector, Major Ricardo Seco. Colonel Lino Sanchez acted as consulting engineer for Major Ruiz. All these gentlemen belonged to the Royal Spanish Engineer Corps.

The excavation for the reservoir was immediately commenced under the charge of Mr. Hector Simonetti. Disappointments occurred at the start from not getting the amount of Decauville plant of track and cars which had been ordered, but work was nevertheless started with all the means at command—plows, ox and mule carts, wheelbarrows, etc. The mule teams were soon discarded; each cart only took about 0.5 cu. yds., and, as it was made fast to the shafts, the harness had to be unbuckled to allow the shafts to be raised in order to dump. The oxen did somewhat better; the carts took 0.75 cu. yds. and could be more easily dumped, but the oxen were very slow and required much water and two hours' rest towards the middle of the day. Late in March, 1890, some wheel and drag scrapers were received from New York which the men could not at first use, and the wheel scrapers were never used satisfactorily. After the use of the drag scrapers had been acquired, they proved very efficient. By the last of April about 50 000 cu. yds. of excavation had been taken out from the reservoir site and the first section of the pipe line, which also required heavy cutting. Early in May some American dump cars and track were received, and a stationary engine erected, to haul the cars out of the reservoir. During the whole of the work, this engine was the main dependence in getting out the material.

Early in May, 1890, the author returned to the United States to collect plant, engage a force of American masons, and prepare for an active prosecution of the work as soon as the rainy season should be past. Mr. A. G. Midford was engaged as general superintendent of

the work at Palatino, and a gang of masons was made up by him in New York. Four pipe calkers were also engaged, who soon trained a gang of Cuban calkers to do good work. Four pipe derricks and four boom derricks, two with 50-ft. booms and two with 40-ft. booms, two double spring carts and one large sling truck for the transportation of pipe were shipped from New York. The sling truck was intended for handling 42-in. pipe. It may be here stated that in practice the spring carts were found handier even for the large pipe, and the truck was seldom used for this purpose. It was found very convenient, however, on many occasions when heavy objects, machinery, etc., had to be moved. Lead ladles, furnaces, and several double and single drum hoisting engines were procured. A stone crusher and a concrete mixer were also shipped, as well as considerable miscellaneous plant, including a testing machine for the pipes, and a cement testing machine.

The author reached Havana with his assistants early in October, 1890. Work had been continued in excavating for the reservoir and pipe line under Mr. Simonetti, assisted by Mr. Manuel A. Pelaez, a Cuban engineer, until July 31st, when the rains made it expedient to suspend the work.

Many delays occurred at the start incident to the commencing of such a large and complicated undertaking in a foreign country and under foreign direction, so that, although the masons were immediately set to work preparing stone, and doing whatever building they could be put at along the line, it was not until November that laying concrete and masonry commenced at the Palatino reservoir. Fig. 1, Plate XIV, is a view of the work, looking west, as it appeared on January 19th, 1891.

The concrete bottom is 1 ft. thick and was laid in two courses of about 6 ins. each. This was to be covered, later, with a finishing course laid with a slight slope toward the discharge pipes which served to empty the reservoirs. The main course, 1 ft. thick, was continuous over the entire area. It extended beyond the back of the retaining walls a short distance, so as to give a good footing for them, and was put in, generally, about 1 ft. thicker under these walls, as an additional foundation for them. An additional foot and sometimes more was placed under the points where the pillars for supporting the roof were originally intended to be set, the additional thickness

at each point covering an area 6.6 ft. square. This formed a large volume of concrete, in all about 5 500 cu. yds., to be spread in so thin a sheet over so large an area. Great care was necessary in preparing the ground for its reception. The specified thickness was obligatory, and, on the other hand, no extra thickness would be paid for. The ground had therefore to be dressed to as nearly a perfect level as possible at the exact elevation of the bottom of the concrete.

The stone mostly used for this concrete was in every respect admirably adapted for the purpose, being an exceedingly hard crystalline limestone, breaking readily in the crusher with a sharp conchoidal fracture. The sand used for all the work was calcareous, there being no siliceous sand procurable. It was sharp, very clean, and gave excellent results. The bulk of the cement used on the work was an English Portland, extra fine grinding, which gave perfect satisfaction. When shipments were delayed, foreign Portland of various brands was bought of the Havana dealers at naturally higher figures. Toward the end of the work, a considerable amount of American Portland was used, with good results. The reciprocity treaty coming into effect at that time made it very desirable to use American materials, as far as possible, for economic reasons.

The keeping of the concrete thoroughly wet for long periods of time after being placed was inflexibly insisted upon. This precaution was doubly necessary in such a climate as that of Cuba, and was enforced for all classes of masonry. There was an abundant supply of water, and the work of wetting everything down was carried on by hose, and by boys with large watering pots. Brooms were also in constant requisition to keep all work thoroughly clean, so as to ensure a good bond of the mortar.

The greater part of the concrete was prepared by the mixer. The proportions used were one part of cement, three parts of sand, and six of broken stone. The ingredients were measured out on the platform of the machine, and the cement and sand mixed dry, by hand. The stones were then wet, and each batch shoveled into the hopper in such a way as to secure a homogeneous mixture. The water was added gradually by a man stationed where he could see the finished product as it was fed out into the car, so as to keep it of the right consistency. The concrete was sent down in cars by an inclined plane. As the time for the rainy season approached, it was feared that the concrete floor would

FIG. 1.

FIG. 2.

not be finished before the rains set in, and that consequently much of the unfinished work would be lost. The machine was therefore supplemented by several gangs mixing hand-made concrete, which was neither as good nor as economical as the machine-made product.

As a proof of the good quality of the concrete, it may be mentioned that a large block, 2 or 3 ft. thick, was placed to form the bottom of a receiving basin adjacent to one of the overflows. This basin was built upon a fill, and, although every care was taken to consolidate the earth filling, it began to show signs of settlement. It became necessary to remove the basin and excavate to the natural ground for a new foundation. The concrete was less than three months old when it was removed, and in that time had become so hard that powder was needed to get it out. It came out in large blocks, some fully half a cubic yard in size, and these blocks were dogged and lifted out by the derrick, and afterwards used as blocks of stone in the new foundations.

In executing the masonry work great difficulty was experienced in getting sufficiently large stones for rapid work in the rubble masonry. The quarries were badly worked by the parties furnishing the material, who were without proper appliances for the purpose. All the stone used in the rubble and cut-stone work might probably be classed as coral limestone and limestone conglomerate, a good quarry of this latter being found in the immediate vicinity of the work. The material for cut stone could be obtained in almost any size desired. It was a peculiar class of the above-mentioned coralline, very soft and easily cut by stone axes into any required shape. It was quarried by chopping channels with axes, and then wedging the blocks out. It was easily worked, but was naturally an inferior material as regards durability.

The inside faces of the reservoir walls were plastered with one part cement, one part sand and one part lime. The author objected to the use of lime, but as this was a mixture ordered by the director, it was, of course, put in. It stood well, however, and, so far as the author knows, is still standing. The floor of the reservoir was finished with a plastering of one part of cement and two of sand.

After the first bed of concrete, 1 ft. thick, was placed, concrete blocks about 5 x 5 x 1.3 ft. were set for the bases of the granite pillar blocks, in case they should be wanted. These blocks were brought up to their

exact elevation, and when the last layer of concrete was applied, which was laid with a sloping surface, the proper height for the finished surface was marked upon each block, and served to keep a true grade for the floor.

Work when fairly commenced was vigorously prosecuted. The great drawback was the impossibility of getting the excavation out fast enough for the concrete and masonry, Although the bulk of the excavation had been taken out the previous season, there still remained a great deal to do to get out and down to the outside lines of the work, especially as the bank, which was generally about 20 ft. high, occasionally caved in. The material had frequently to be handled over more than once, because it was necessary to get out the foundations faster than the earth could be removed from the site. The great reliance in hoisting out the earth was the inclined plane operated by the stationary engine, but scales and derricks were also used. The loaded dump cars were also swung out of the pit bodily by a strongly guyed derrick, landing them on a track on the bank, whence an ox team would take them off to the dump and return them to the derrick. It would have been good judgment to have had two engine planes for the removal of the material, but this fact was not realized until it was too late to send to the United States for the necessary plant.

The rain caused great delays. The author had been led to believe, both by common report and his own experience on previous visits, that the winter months would be quite free from rainfall, and so, in general, it is believed they are, but during this and the succeeding year copious rains fell at intervals through the winter months, and between the legitimate rainy seasons. On the other hand, in June, 1891, dry weather occurred where rain had been anticipated and provided for by putting on extra gangs, at a heavy expense, to complete the concreting of the floor before June 1st. As it proved, this extra expense might have been spared, but this was only by a chance, which could not have been counted on.

The original drawings showed a uniform section of retaining wall for all four sides of the reservoir. It was evident, however, from the nature of the ground that the pressure would be greatest upon the south side. Accordingly, some counterforts were built into the back of the wall, as a palliative measure for its lack of stronger section. In spite of this precaution, a portion of the unfinished south wall ad-

vanced bodily into the reservoir, forming the arc of a circle, with a versed sine of not quite 6 ins., the wall otherwise showing no apparent change of form. The earth was immediately removed in part from behind it to relieve the pressure, and no further movement took place, a few slight cracks only being visible on the face. This circumstance, under the peculiar laws regarding responsibility, threatened to become an embarrassing one, but the matter was finally decided by the authorities in a spirit of fairness. Enough of the injured wall was taken down to remove the cracked portions, and to enable the top to be rebuilt on a straight line. Advantage was taken also of the opportunity to increase the dimensions of this part of the wall so as to insure against a repetition of the disaster. In removing the damaged portions it was necessary to use light charges of powder. In fact, this mishap rendered very conspicuous the excellence of the materials and work put into the wall.

Late in August, 1891, the work was suspended for the season, the concrete flooring being completed, with the exception of the finishing course, and the retaining walls on all sides finished with the exception of a gap left for drainage and some intervals left for subsequent construction.

Work was resumed early in November of the same year, and carried on vigorously, although there was a great deal of rain both in this and the following month. It was now determined to dispense with all help brought from the United States, and from the suspension of the work in August to its completion only local help was employed, with the exception of a few Italian-American masons, who had drifted down on their own responsibility.

In February of 1892 the author's principal assistant, Mr. Victoriano García San Miguel, a Spanish officer of engineers, returned to Spain, and his place was taken by Ernesto J. Balbin, M. Am. Soc. C. E., who had previously been assistant to the director, Major Ruiz.

After the resumption of the work the center wall was built, as well as the influent and effluent gate chambers. This last was an extensive and imposing structure. It comprised much cut-stone work. Fig. 2, Plate XIV, is a view of the work looking southwest, which was taken May 13th, 1892. It shows the work of concreting of the bottom with both hand and machine-made concrete, and the beginning of the construction of the effluent gate chamber.

Early in November, 1892, rather less than two years from laying the first stone, the work was practically completed, with the exception of some exterior work, and both tanks were filled with water, experimentally. Everything proved to be all right. In January, 1893, the principal part of the piping of the city having been completed, the reservoir and pipes were filled, preparatory to the official inauguration of the works. This took place January 23d, under the auspices of the Captain General and Bishop of Havana. Fig. 1, Plate XV, is a view looking north down the center wall, when both tanks were full. It was taken January 21st, 1893, two days before the inauguration. Fig. 2, Plate XV, is a view of the completed work, except grading and iron gates in openings in the wall surrounding the reservoir.

The final estimate for the Palatino Reservoir is as follows, the quantities being reduced to English measures and the prices paid to American currency:

Excavation	89 474	cu. yds. at	$0 70	$62 631 80
Embankment	126 983	" "	0 49	62 221 67
Terracing	30 796	" "	0 42	12 934 32
Concrete	8 860	" "	15 22	134 849 20
Rubble, 1st class	10 576	" "	12 78	135 161 28
" 2d "	272	" "	10 88	2 959 36
" 3d "	946	" "	7 57	7 161 22
" arches	96	" "	13 00	1 248 00
Cut stone, cornices	57.31	" "	38 94	2 231 65
" bridge stones	69.47	" "	37 84	2 628 74
" patterns	1 186.66	" "	33 72	40 014 18
" plain	597.50	" "	29 52	17 638 20
" 2 beds	410.00	" "	25 23	10 344 30
Brick	741.00	" "	17 09	12 663 69
Dry stone	296.00	" "	5 26	1 556 96
Plastering, 1st class	5 448	sq. yds. at	1 51	8 226 48
" 2d "	19 540	" "	0 92	17 976 80
Paving, concrete	1 424	" "	2 29	3 260 96
" brick	690	" "	1 15	793 50
Face work on cornices	106	" "	2 75	291 50
Graveling terrace	500	" "	0 69	345 00
Tile drains, 1 305 running feet		"	0 67	874 35
Timber grillage, 10 100 ft. B. M		"	28 60	288 86
Gates, valves, etc				13 832 41
Iron work, stairs, railings, etc				12 434 81
Miscellaneous				1 917 27
Total				$566 486 51

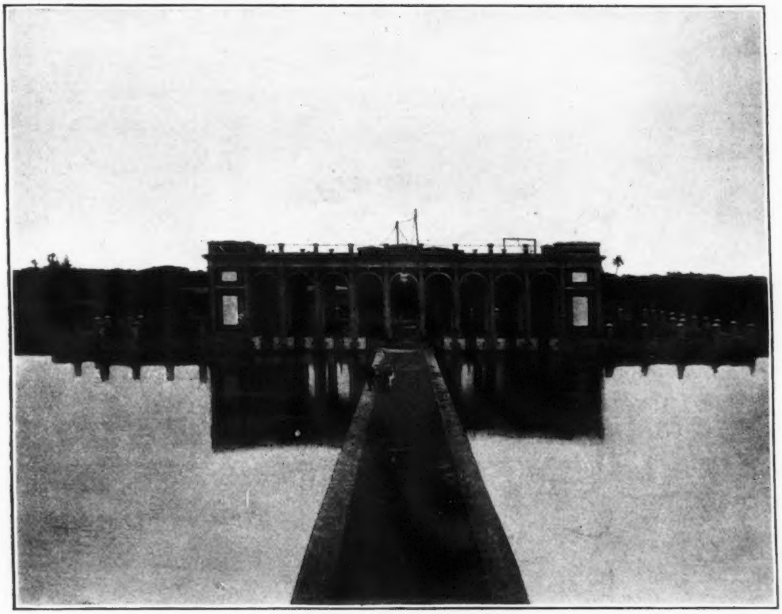

FIG. 1.

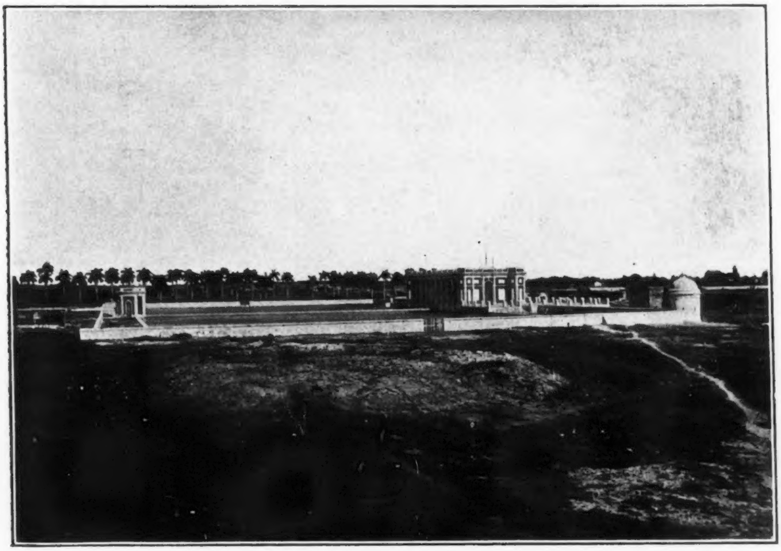

FIG. 2.

The quantities and prices, in English measures and United States currency, of the pipe system, according to the final estimate, were as follows:

Cast-iron straight pipe, 7 930 tons at $85 39.....	$677 142 70
Lead, 320 682 lbs. at 6 cents....................	19 240 92
Hauling, 7 930 tons at $2 50....................	19 825 00
Pipe laying, 465 655 lin. ft. at $1.022 (average price)	475 899 41
Gates, valves, hydrants and various specials, 88.19 miles at $1 272......................	112 177 68
House connections and services, 88.19 miles at $760 10..........	67 033 22
Masonry, earthwork, pile-driving, etc., on 42-in. pipe line, 2.51 miles at $60 025 50...........	150 664 00
Unclassified	44 391 65
Total...............................	$1 566 374 58

The manner of making up the engineer's estimate for this class of public works, according to Spanish rule, is to calculate as nearly as possible the actual cost at which it can be done, and then add 19% for contractor's profit. In the above statement, the 19% is added in for each item separately, as giving a clearer idea of the actual prices paid.

The length and weight of pipe, and the weight of the lead used for the different diameters, were as follows:

Diameters. Inches.	Length. Feet.	Weight. Tons (2 240 lbs.).	Lead. Pounds.
42................................	13 236	2 380	88 950
20................................	21 650	1 273	61 812
12................................	26 858	797	47 751
8................................	34 712	590	3 042
4................................	338 431	2 715	113 566
3.......	30 768	175	5 561
Totals....................	465 655	7 930	320 682

The construction of the Palatino Reservoir was under the author's exclusive charge, and he held, also, the position of consulting engineer for the entire enterprise covered by the contract of Messrs. Runkle,

Smith & Co. The pipe laying was under the immediate charge of Mr. Simonetti.

Four pipes ran out from the collecting pipe in the effluent gate chamber. One 12-in. pipe was for the supply of the Cerro district, adjacent to the reservoir; one 20-in. for that of the Jesus del Monte district, also near by; another of 20 ins. diameter, to be connected, if necessary, with the old or Fernando Sétimo system, and the main 42-in. pipe for the general supply of the city. This last pipe extended about 2½ miles, crossing two valleys on masonry arcades, not included in the estimate for the reservoir, to an elevated point in the city, whence branches were run through the various streets.

The service pipes of wrought iron rapidly corroded in the impure soil in which they were laid, and were the cause of much trouble and expense for renewals.

The author desires to acknowledge his indebtedness to the gentlemen already named as connected with him in the work for the faithful, zealous and efficient co-operation which they rendered him in carrying out the undertaking. He is also indebted to Mr. Pelaez for the historical data given in the beginning of this paper.

Besides those whose names have been already mentioned, J. A. Ruiloba, Jun. Am. Soc. C. E., Mr. Fortun, a Cuban engineer, and Mr. Domingo Del Monte, were at different times employed on the work, and all did well in their several capacities.

The benefits accruing to the city of Havana by the execution of this work have been enormous. An abundant supply of exceptionally pure water has been introduced into all parts of the city, including those districts which previously were unprovided with any water except what was brought in pails from public plugs. It is true that, as the draught upon the supply increases, the pressure diminishes, and inconvenience has been already experienced from this cause. This inconvenience was apprehended and pointed out by the author when the work was commenced, and a diameter of 48 ins. recommended for the 13 236 ft. of main running out of the reservoir, instead of the 40 ins. originally contemplated. The extra cost was regarded, however, as prohibitive, and a diameter of 42 ins. was finally settled upon. The 48-in. main would in this distance have given over 15 ft. additional head at the point where the smaller mains branched off. That is, the calculated piezometric head at this point being at

elevation 83.6 ft. with a 42-in. main, would have been at 99 ft. with one of 48 ins., a gain of about 18%, which, under the circumstances, would have been of immense benefit.

As a growing interest is taken in work in Spanish American countries, some general reference to this class of enterprise may be looked for in this paper. The experience and observation of the author in Cuba and elsewhere lead him to the following conclusions:

First.—The hope of reaping extravagant profits from such undertakings must not be entertained. No matter how favorable the contract or concession may be, a host of unforeseen difficulties are sure to arise owing to many causes, the partial enumeration of which, even, cannot be entered into here.

Second.—The work must be carried on with precisely the same economy, energy and attention to detail which would be considered essential to success at home.

Third.—As far as possible local help and materials should be employed, and methods of work made to conform to local usage.

Fourth.—No such enterprise should be undertaken unless sufficient capital has been secured to plan, start and carry on the work rapidly and vigorously. The author is convinced that the striking success which, in spite of all obstacles, crowned the work just described, was very largely due to the sound and liberal basis upon which the undertaking was financed by its promoters.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

PAPERS.

THE RECONSTRUCTION OF GRAND RIVER BRIDGE.

By W. A. ROGERS, Jun. Am. Soc. C. E.

TO BE PRESENTED OCTOBER 7TH, 1896.

The reconstruction of the bridge over Grand River, 3 miles south of Chillicothe, Mo., on the Kansas City Division of the Chicago, Milwaukee and St. Paul Railway, by the railway company's Bridge and Building Department, presents several interesting features which will be described by the author, who was the engineer in charge of the work.

The Kansas City Division was built west from Chillicothe during the year 1887. The crossing of the Grand River consisted of a pile approach 1 070 ft. long at the east end, four 138-ft. wooden Howe truss spans across the channel, and a 16-ft. pile approach at the west end. The Howe trusses rested upon pile piers, each consisting of 48 oak piles well braced, planked on the outside, filled with rock and riprapped at the bottom. That these piers were well built is shown by subsequent events. Grand River, at the ordinary stage of water, is

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

about 150 ft. wide at the bridge, and from 4 to 6 ft. deep. It is subject, however, to very sudden rises, ranging from 10 ft. to 29 ft. above low water. At times of high water the current is very swift and carries large quantities of driftwood.

In 1894 it became necessary to renew the east pile approach, and it was decided that the Howe trusses must be replaced during the succeeding year. The wooden piers were in fair condition, and, inasmuch as they were good for at least two and possibly three more years, it was also decided that it would be best to replace the Howe trusses with iron spans of the same length, erected on the old piers, and then, when it became necessary to do so, to build new piers as near as practicable to the old ones, and on their completion to transfer the iron spans to them, the plan being to carry the wooden trusses as they were until the end of June, 1895, then to put in falsework and erect the iron during the fall. It was considered unwise to put falsework or strengthening bents under the trusses before this time on account of the danger from driftwood in case of high water. Grand River usually has a high June rise and is expected to stay at a comparatively low stage from then until some time in January.

During March, 1895, the second span from the east began to show evidence of weakness and three strengthening bents were driven under it as a measure of safety. The spring and summer were exceptionally dry, the usual June rise did not occur, and about July 1st it was thought to be safe to begin the falsework preparatory to taking down the spans and erecting the iron in the fall. This was started somewhat earlier than was necessary for iron erection purposes because the timber seemed to be deteriorating faster than had been expected. As a precautionary measure in case of high water, it was to be built last under the third span from the east, that being the channel span. During the middle of August a rise of the river occurred without serious consequences. On August 28th, the falsework was in the following condition. It was complete under the two east spans, and there was a bent of falsework at the third panel point from each end of each of the two west spans. At that date the river began to rise very rapidly, bringing down large quantities of brush, logs and whole trees, and did not stop rising until it had reached a stage about 20 ft. above low-water mark. In spite of all that could be done a jam was started at the bridge, against the falsework, which rapidly increased in size until a

mass of this driftwood from 4 to 12 ft. in thickness, extending the full length of the spans and 700 ft. up the stream, was lodged against the piers and falsework. One of the bents of falsework was carried away and one of the piers was thrown 8 ins., and another 5 ins. out of line at the top. A view of the accumulation of drift is shown in Plate XVI, Fig. 1.

On examination it was found that the piers were not undermined by the current, but seemed to have been simply bent out of line by the great pressure exerted against them. They were apparently uninjured by their rough usage during the high water. The river subsided rapidly to its normal depth, leaving a large part of the driftwood on the sand at the sides. It was so intricately interwoven that it was impossible to separate a piece without cutting it loose from the rest.

The lodging of this immense amount of driftwood against the bridge put a new aspect on the situation, and in view of all the circumstances it was decided to begin the erection of the new spans as soon as the iron could be obtained from the bridge works, in order to permit taking out the falsework and clearing the channel, and instead of carrying the iron on the old piers for two or more years, to begin at once the construction of the new ones. It was decided also that the second, third and fourth piers from the east should be built of stone and the first and fifth should be pile piers. The two last are on the banks out of the line of the swiftest current. The piers were located, beginning at the east, respectively 29 ft. 7½ ins., 29 ft. 9 ins., 30 ft., 30 ft. 3 ins., and 30 ft. 4½ ins., east of the old piers (see Fig. 1). This was as close to the latter as it was convenient to work. On their completion the spans were to be moved endwise to their proper position on the new piers. It was with these problems confronting the Bridge and Building Department that the actual work of reconstruction was begun.

The first thing to be done was to finish building the falsework and traveler runway for erecting the iron and to take down the Howe trusses. This was done in September, and in the middle of October the iron crew began building their traveler, but were unable to begin the actual work of erection until November 1st on account of delays in getting the material. These were due in part to the difficulty the bridge works had in obtaining the required shapes from the mills, on account of the number of orders on hand, and in part

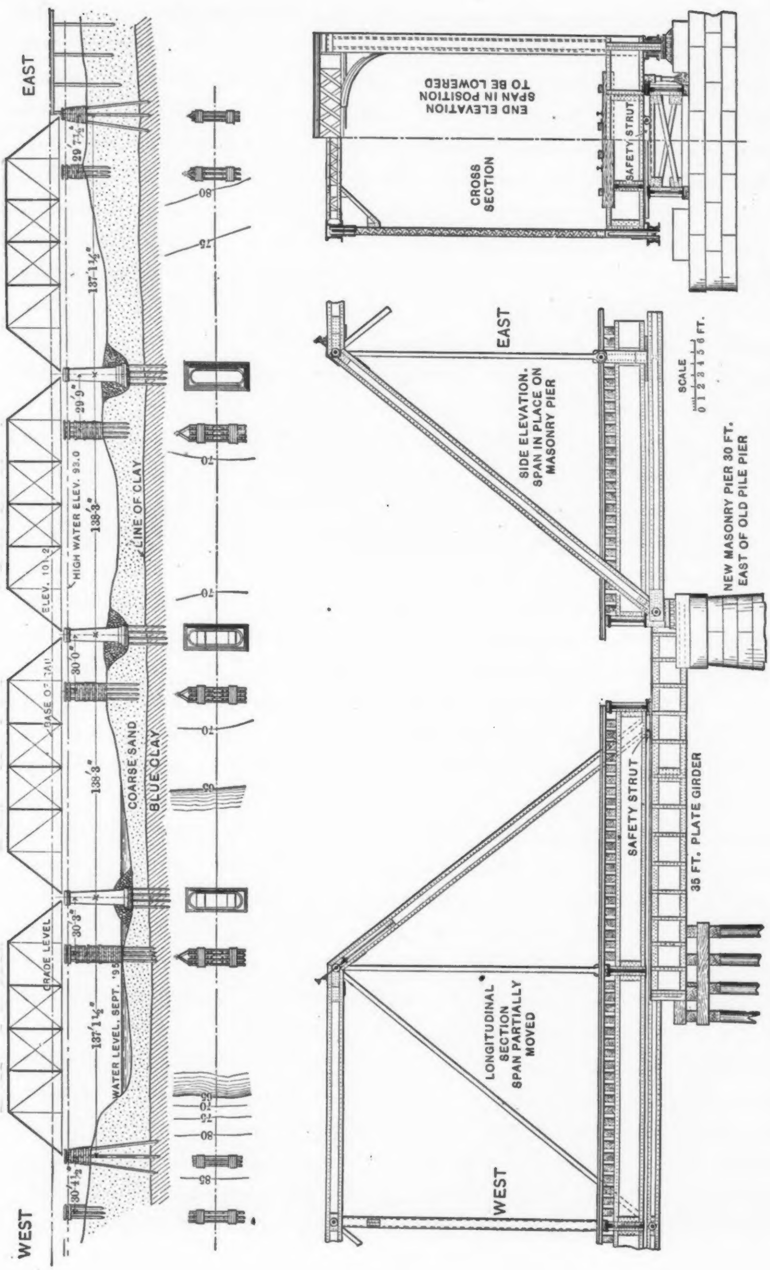
EAST
WEST
GRADE LEVEL
BASE OF RAIL
ELEV. 101.2
HIGH WATER ELEV. 93.0
WATER LEVEL, SEPT. '95
COARSE SAND
BLUE CLAY
LINE OF CLAY
137' 1½"
138' 3"
138' 3"
137' 1½"
END ELEVATION SPAN IN POSITION TO BE LOWERED
CROSS SECTION
SAFETY STRUT
SIDE ELEVATION. SPAN IN PLACE ON MASONRY PIER
SCALE 0 1 2 3 4 5 6 FT.
NEW MASONRY PIER 30 FT. EAST OF OLD PILE PIER
SAFETY STRUT
35 FT. PLATE GIRDER
LONGITUDINAL SECTION SPAN PARTIALLY MOVED

FIG. 1.

to the scarcity of cars for transporting the iron from the shops to the bridge site. This work was being done at a time when every car was needed to carry on the business of the railroad. Notwithstanding these delays, on November 19th the spans were all erected and riveting finished. The erection of the spans did not present any particularly interesting features. The four spans weighed 714 489 lbs., and the cost of iron and erection combined was 2.73 cents per pound. The cost here includes, as in all other cases where it is given, the amount paid in wages to the railway company's employees, and the cost of the material delivered at the most convenient point on the company's lines, and no other items. Iron and stone were purchased by weight, and timber by board measure, free on board cars on the company's lines.

Many schemes for disposing of the driftwood and clearing the channel were proposed. Several contractors asked permission to bid on the work, and offers ranging from $1 900 to $14 000 were made. It was decided, however, that the railway company was as well equipped for the work as any contractor; that it could do the work, which would be as novel to the contractor as to it, just as cheaply; that there was considerable uncertainty as to the cost; some risk to the bridge in case an attempt to burn the drift should be made, and that, all things considered, it would be unwise to contract for its removal. On November 11th the work of removal was begun in an experimental way, with the understanding that it should in no way be allowed to interfere with the building of the masonry. In preparing the foundations it was necessary to remove considerable drift which had lodged on the site of the new piers. This was done largely by hand and by teams, the wood being hauled to one side, piled and afterward burned. On November 14th a small crew of men and teams started to clear that which was piled against the wooden piers on the east side of the channel. The plan was to pull all of it which had lodged against the piers from them first; next to clear a space alongside and parallel with the bridge, in order to remove any danger in case it was decided to burn the wood, and then to set fire to a part of it to see if it would burn in a body. The method of procedure was to drag the logs with teams through the bridge to the sand bank below, after loosening them by chopping and the use of blocks fastened to the bridge. Fires were kept con-

PLATE XVI.
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AUGUST, 1896.
ROGERS ON GRAND RIVER BRIDGE.

FIG. 1.

FIG. 2.

tinuously burning the wood thus hauled, so that each night practically all which had been hauled out during the day was consumed. There was considerable fine stuff, twigs, small branches and cornstalks in with the logs, which caused much trouble, as it all had to be picked out by hand and hauled to the fires in wagons. It had to be taken out, however, in order to get at the logs.

On November 21st the driftwood around the piers east of the channel, and also a strip about 30 ft. wide parallel with the bridge, had been disposed of. The wind was blowing strongly from the bridge, and after trying one corner of the driftwood it was decided to set fire to all of it lying east of the channel. About 2 o'clock in the afternoon, after placing a steam-pump and 250 ft. of hose to protect the bridge, fires were started on the side next to the bridge and along the channel in a large number of places. In a few minutes the whole mass was in a blaze. It was a magnificent sight, burning rapidly, but without high flames or sparks. From time to time the wooden piers were wetted down to prevent their catching fire. By 6 o'clock in the afternoon the fine stuff was practically all consumed, and the logs were burning well, and it was in such shape that it was safe to let all but six men and the pump engineer go home for the night. The fire cleared up the driftwood east of the channel in good shape, except that here and there a pile of it was left unburned, and at the upper end quite a large section did not burn at all, due largely to the fact that the wind changed about the time the fire reached it, blowing the flames away. The fire did not cross the river.

The wood left unburned east of the channel was next collected, the idea being that after clearing each side of the channel it would be unnecessary to touch that which was in the water, as in case of high water it was expected the current would cut a new channel in the cleared space provided on the east side. This has been partly proved, as, during a small rise which occurred during the latter part of December, the river started to cut a new channel along the east side of the driftwood left in the water. This is an advantage, as it will stop the undermining of the west bank. The driftwood was cleared from the west pier, and on November 27th fire was set to that on the west shore. It did not burn as well as that on the east side on account of the fact that there had been snow. Some experiments were made with crude oil, but with little success. After disposing of

the drift on each side of the channel the long logs lying in the channel which were accessible were cut up, and it was considered perfectly safe to suspend work upon it.

It was believed that inasmuch as this driftwood came down at a stage about 20 ft. above low water, very little more would come down until the same stage was reached again, and that as soon as the river began to rise the remaining drift would begin to float off, and by the time the river was high enough to bring any more, that lodged in the river, now there were no obstructions, would have floated away.

The cost of disposing of the driftwood was very small compared with the lowest estimate, the total cost for labor and material used being $938 78.

It was thought best to wait until the east iron span was erected before beginning the construction of the masonry, in order to avoid the confusion incident to two crews working at one end of the bridge at the same time. The east pier was selected to begin with on account of the necessity of locating the stone yard on the level ground just east of the east span. The stone was unloaded directly from the cars to the stone yard by a hand-power derrick, except for a short time toward the completion of the work when steam power was used. The pile bridge was of such height that the work of the yard derrick in unloading and piling the stone was lowering. Raising stone to any considerable height by a hand-power derrick is very expensive. The stone was delivered from the stone yard to the piers by a push car running on an elevated track made of timbers taken from the trusses and built so as to pass close to the south end of each pier. It was on the ground at the stone yard and was given enough grade so that the car loaded with stone needed only one man to manage it. The stone on the car at the pier was of such height that the work of the setting derrick was all lowering except for a few of the top courses.

The soil at the site of the three masonry piers consists of coarse sand extending to about 10 to 12 ft. below low water and then a stratum of blue clay. The foundations of the east and middle piers consist of 44 pine piles each, from 19 to 23 ft. long, extending from 10 to 16 ft. into the clay. The piles are cut off 2 ft. 2 ins. below low water, capped with 12 x 12-in. pine timber, and these covered with a platform of 8-in. timber. The piles were driven with a steam-power land driver, having a 3 000-lb. hammer, aided by a water-jet. The

latter was of material assistance in driving the piles through the sand. A 6 x 5¾ x 6-in. duplex Worthington pump with a 4-in. suction and a 2½-in. discharge was used to furnish water for the jet.

The foundation of the west or channel pier consisted of 44 pine piles from 21 to 23 ft. in the ground and cut off 4 ft. below low water. On these piles a caisson was sunk made of three thicknesses of 8-in. timber for the floor and 3-in. plank for the sides. Most of these plank had been used in the falsework as sway braces, and most of the piles used in the foundation of the three piers had also previously been used in the falsework. The masonry had courses ranging in thickness from 15 to 26 ins. with beds and joints not exceeding ⅜ in. Western Portland cement was used to set the footings, the lower three neat work courses, the coping and bridge seat stones. The rest of the courses were laid in Milwaukee cement. The mortar was composed of one part of cement to two parts of sand by actual measurement. The sand was obtained at the site and was an ideal mason sand. The stone used is a limestone obtained at Stone City, Ia., and is the stone which this railway company has principally used for its bridge work for some time past. It is soft, easily cut, and very durable. Frost has little effect on the ledges used for the company's work. Displacement of the hip stones when struck by logs or driftwood is prevented by securing each by one or more dowels extending about 8 ins. into the course below.

The foundation work was begun November 5th, 1895, and was completed January 2d, 1896. The stone cutting for the piers was begun November 7th, 1895; setting stone on the east pier was commenced November 24th, and the masonry was finished January 18th, 1896. The total cost of the foundations of the three piers was $2 374 40, or an average cost of $18 per pile driven. There are 715 cu. yds. of masonry, costing $5 747 30, or $8 04 per cubic yard. The cost per cubic yard, including the cost of foundation, was $11 36.

In designing the iron spans, the fact that they were to be moved longitudinally after erection was considered and the plan of moving was decided upon. In furtherance of this plan, the end floor beams were to be attached to the end shoes by means of vertical angles in such a way that the spans could be lifted and carried by them, the plan of moving being to pull the spans, one at a time, on small rollers running on the top of a 35-ft. iron girder span reaching from the old

to the new pier at each end of the span being moved. For this purpose two 35-ft. plate girder spans were constructed after the general plan of one of the company's types of deck girder spans, except that the weight was increased about 14%, and on the top of each girder a $\frac{3}{4}$-in. plate 10 ins. wide was riveted with countersunk rivets. The girders were spaced 9 ft. center to center. The cross-frames and laterals were to be connected by means of bolts, so that the girders could be placed in position, bolted up, and after use unbolted and taken out separately. These girders are to be put in service as ordinary bridges now that the spans have been moved. Twenty-eight $2\frac{1}{2}$-in. rollers, with shoulders projecting $\frac{1}{4}$ in., were made to run on the top of the girders. These rollers were $10\frac{1}{8}$ ins. between shoulders, and 12 ins. long over all. They were made to fit the plate on the top of the girders closely, so that they would run true while in use. Four shoes 12 ins. long and 10 ins. wide, to be clamped to the lower flange of the end floor beams directly above the moving girders, were made to fit between the shoulders of the rollers. Two struts of two 6 x 4 x $\frac{5}{8}$-in. angles each were clamped to the lower flanges of the stringers a short distance from the end of the floor beams. When in position, with the span raised and resting on the rollers, each strut extended over the top of the moving girders, clearing the top plate $\frac{1}{4}$ in. both above and at the side. Its province was to catch the span after a drop of $\frac{1}{4}$ in. and to prevent any lateral motion in case the shoes ran off the rollers.

Wooden shores were to be placed between the top of the second floor beam from each end and the top chord to prevent buckling of the span in this case. Fig. 1 shows a span partially moved and gives the details of the moving device. Each end of the span in process of being moved was to be raised by means of four 25-ton hydraulic jacks, two on each side, under the end floor beams, between the moving girders and the end shoes. The rollers were then to be placed under the shoes on the girders and a locomotive attached to the span to pull it ahead. The plan contemplated was to pull the spans one at a time at intervals measured by the length of time necessary to take up the moving girders at the front of the span last moved and to place them in position under the rear of the span next in order. Each moving girder span between the truss spans would carry the rear end of one span and the front end of the next span without being shifted. During the intervals, after moving one span and while preparing to move

the next one, the track between these two spans was to be carried on blocking resting on the moving girder span in position between them.

The ends of the girders resting on the new piers were placed at such a height that when the truss span had rolled into position it would be 0.5 in. higher than when lowered to the pier. The other ends on the old piers were raised 1 in. higher, in order to give a down-grade to assist in the moving. This was effected by putting shims of the proper thickness under the ends of the girders resting on the new masonry piers and on the wooden piers at the expansion ends and by cutting down to give the proper elevation at the fixed ends. Between February 1st and 8th all work preliminary to moving the spans was completed and everything put in shape, so that when the moving was once started there would be no delays on account of lack of preparation. On the afternoon of February 8th, which was Saturday, the track ties between the east new pier and the east old one were cut off and the stringers shoved in far enough to permit setting the first girder span early in the morning of February 10th. The first thing done on that date was to set in place the girders of this span, using the derrick cars which have been specially designed by the Bridge and Building Department for iron bridge erection. This span was to carry the front end of the east truss span. After landing these girders, those for the rear end of this span were put in place, which was a more difficult task, inasmuch as the girders were 35 ft. long and the truss panel length was only 22 ft. 6 ins. It was accomplished by leading them endwise, by means of the derrick cars, through the end panel between the batter post and the hip vertical.

The two girders at the front end of the span and one of those at the rear end were lowered into position by noon. In the afternoon the other girder was placed, the cross-frames and laterals of both spans put in and the bolting up almost completed. During the next morning this work was finished and the girder spans were centered exactly to position. The center of the end on the old pier was made to coincide with the center of the truss, and the end on the new pier was centered with reference to the center line desired for the new position of the bridge, which was $1\frac{1}{2}$ ins. south of the old center line. This would cause the spans to move laterally $1\frac{1}{2}$ ins. while going 30 ft. longitudinally.

The piles between the east end of the truss span and the east new pier were cut out and the track blocked up on the moving girder span. The tackle with which the locomotive was to do the pulling was fastened to the end batter posts and laid ready for use. Everything was made in readiness to move this first span between 12.45 P. M., when a passenger train was due from the west, and 3.20 P. M., when another passenger train was due from the east. After the passage of the train at 12.45 P. M. the track was torn out ahead of the span and the material piled at the east end of the second span, in the order in which it would be needed to block between the first and second spans. While the carpenter crew was doing this work the iron crew was engaged in jacking up, first the east and then the west, end of the span, clamping the roller shoes on the lower flanges of the end floor beams, then lowering them down on the rollers placed on top of the girders. The safety struts were put in place and the locomotive attached to the steel cable by which the span was to be moved. This cable was attached at one end to the batter posts a short distance above the level of the track. It was so arranged with a double and triple block as to give six parts to the line. This was done to reduce the speed of moving slower than it would be practicable to run the locomotive. The other end was fastened to a chain which was attached in turn to the drawhead of the locomotive by passing a coupling pin through one of the links. In order to stop suddenly if it were wished to do so, block and tackle were fastened between the rear batter posts of the span to be moved and the front batter posts of the next span, and men stationed at these lines for that purpose. The force was placed as follows:

The conductor and brakeman of the work train near the engine to pass the signals to the engineer.

Three men to look after the moving tackle.

Two men at each moving shoe, one of whom fed the rollers in front of the shoe as the other passed them to him as they came out behind; each shoe rested on five rollers, thus leaving two extra ones.

One man stood at each end of the span where he could watch the operation of the rollers at his end and give signals to regulate the speed when necessary.

Two men were detailed to pay out the snub lines at the rear.

One man was sent out in each direction to flag approaching trains.

The carpenter foreman and crew of eight men were stationed at the front end of the second span to block up on the moving girders and to put in the temporary track as fast as the gap behind the span opened.

At 1.43 P. M. the locomotive started to pull the span and at 2.02 it had reached its proper position ready to be lowered to the new piers. At 2.40 P. M. the spans were let down on the piers, the track connected up at the east end of the span and everything in shape for traffic. At 2.55 P. M. an eastbound freight train crossed the bridge. The actual time during which the track was disconnected was 1 hour and 55 minutes. The time consumed in pulling this first span across the distance from the old to the new piers was 19 minutes. The girders at the front end of this span were picked up and loaded on the cars before night, ready to set down at the rear of the second span the next morning. Those in the rear of the first span were all ready to carry the front of the second span.

The next day the weather was bad and no work was done. On the following morning the girders were lowered into place at the rear of the second span. This span was moved after 3.20 P. M. the same day. The operation of moving the second, third and fourth spans was practically the same as that of moving the first. The last two spans were moved on February 14th and 15th respectively.

TABLE GIVING TIME CONSUMED IN MOVING EACH SPAN.

Span number from east.	Date when moved.	Track was disconnected at.	Started to pull span at.	Span reached new position at.	Track ready for traffic at.	Length of time track was impassable.	Length of time required to pull span from old to new position	Distance moved by span.
		P. M.	P. M.	P. M.	P. M.	H. M.	Min.	Ft. Ins.
No. 1...	February 11th, 1896....	12.45	1.43	2.02	2.40	1 55	19	29 7⅞
No. 2...	" 13th, "	3.30	4.06	4.16	4.45	1 15	10	29 10
No. 3...	" 14th, "	3.30	4.18	4.24	4.55	1 25	6	30 1
No. 4...	" 15th, "	3.30	3.49	4.16	4.50	1 20	27*	30 4⅛
	Average..............	....	....	....	....	1 20	15½	

* Fifteen minutes' delay due to a shoe working loose and becoming skewed.

A view of the last span when half moved is shown in Plate XVI, Fig. 2.

On February 17th the girders were picked up and loaded on the cars for shipment.

The time consumed in moving the four spans was 6½ days. The locomotive used was a Rhode Island 17 x 24-in. cylinder, eight-wheel engine, weighing 86 150 lbs., 54 450 lbs. on the drivers. The engineer reported the pull to be very light. There was no trouble in starting or stopping.

The total cost of moving the spans was $716 81, or an average of $179 20 per span. After moving, the track was lined, the floor finished, the old piers removed and their rock filling used to rip-rap the new piers. Everything was finished March 15th, 1896. A statement showing the cost in detail is given at the end of the paper.

During the reconstruction of this bridge there were no delays to passenger trains and rarely to freight trains, and these never exceeded ten minutes. During the erection and moving of the iron spans each train was required to come to a full stop during working hours and receive a signal before crossing the bridge, and to reduce speed while crossing the bridge during the night. The rest of the time trains reduced speed during working hours only.

Notwithstanding the unusual character of part of this work it was all done on week days. Experience in the Bridge and Building Department has shown, aside from questions of principle, that as a rule Sunday work is more expensive and no safer than that done on week days.

Plans and specifications, including all working drawings, were made by the Bridge and Building Department of the Chicago, Milwaukee and St. Paul Railway Company. All work at the bridge site was performed by the company's employees, and every item of construction from beginning to end was carried out by the department.

CONDENSED STATEMENT OF COST.

FALSEWORK, TAKING DOWN HOWE TRUSSES AND REPAIRING OLD PIERS.				
Labor		$1 834 99		
Train service		150 00		
			$1 984 99	
Material			1 606 90	
				$3 591 89
TWO PILE PIERS.				
Labor		$287 00		
Train service		40 00		
			$327 00	
Material			420 24	
				747 24
THREE MASONRY PIERS.				
Foundation—				
Labor		$1 773 00		
Material		601 40		
			$2 374 40	
Stonework—				
Labor		$3 485 53		
Material—				
232 sacks Western Port. cement	$109 65			
269 sacks Milwaukee cement	67 25			
34 308 cwt. bridge stone	2 061 93			
Miscellaneous	22 94			
		2 261 77		
			5 747 30	
				8 121 70
IRONWORK.				
Labor erecting		$1 952 97		
Train service		96 78		
			$2 049 75	
Material—				
100 009 lbs. wrought iron		$1 7216 91		
14 489 lbs. cast iron		195 43		
Miscellaneous		21 06		
			17 433 40	
				19 483 15
FLOOR.				
Labor			$292 82	
Material			1 051 32	
				1 344 14
MOVING THE SPANS.				
Labor		$521 99		
Train service		58 20		
			$580 19	
Material—				
2 523 lbs. iron (shoes, struts, etc.)		$69 38		
2 445 lbs. iron (increased weight of two moving girder spans)		67 24		
			136 62	
				716 81
Removing old piers, pulling piles, taking out falsework				593 05
Removing driftwood				938 78
Night watchman				465 50
Engineering, office expenses and inspection of stone and iron				1 145 96
Total cost				$37 148 22

Analysis of Cost.

The falsework, taking down the Howe trusses and repairing the old piers cost $6 53 per lineal foot.

The new pile piers cost $373 62 each.

The foundation of the three masonry piers cost an average of $18 per pile driven.

The stonework cost $8 04 per cubic yard, exclusive of foundation, and $11 36 including foundation. Each cubic yard of finished masonry required 48 cwt. of stone in the rough, and the cost of the labor per cubic yard averaged $4 87.

The erection of the iron spans cost 0.29 cent per pound, and the erection and material together cost 2.73 cents per pound.

The floor of the iron spans, including the heavy iron angle guard rail, cost in place $22 22 per thousand feet, board measure, of timber used, or $2 44 per lineal foot of floor.

The cost of moving the four spans averaged $179 20 each or 0.1 cent per pound.

The engineering, office expenses and inspection of stone and iron formed 3% of the total cost.

Vol. XXII. SEPTEMBER, 1896. No. 7.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publication.

CONTENTS.

SOCIETY AFFAIRS.

PAPERS.

The price of publications is as follows: Proceedings, $6 per annum; Transactions, $10 per annum. Postage will be added when they are sent to foreign countries.

American Society of Civil Engineers.

OFFICERS FOR 1896.

President, THOMAS C. CLARKE.

Vice-Presidents.

Term expires January, 1897:	*Term expires January*, 1898:
DESMOND FITZGERALD,	WILLIAM R. HUTTON.
BENJAMIN M. HARROD,	P. ALEXANDER PETERSON.

Secretary, CHARLES WARREN HUNT.

Treasurer, JOHN THOMSON.

Directors.

Term expires January, 1897:	*Term expires January*, 1898:	*Term expires January*, 1899:
WILLIAM H. BURR,	AUGUSTUS MORDECAI,	GEORGE A. JUST,
JOSEPH M. KNAP,	CHARLES SOOYSMITH,	WM. BARCLAY PARSONS,
BERNARD R. GREEN,	GEORGE H. BENZENBERG,	HORACE SEE,
T. GUILFORD SMITH,	GEORGE H. BROWNE,	JOHN R. FREEMAN,
ROBERT B. STANTON,	ROBERT CARTWRIGHT,	DANIEL BONTECOU,
HENRY D. WHITCOMB.	FAYETTE S. CURTIS.	THOMAS W. SYMONS.

Assistant Secretary, JOHN M. GOODELL.

Standing Committees.

THE PRESIDENT OF THE SOCIETY IS *ex-officio* MEMBER OF ALL COMMITTEES.

On Finance:	*On Publications:*	*On Library:*
JOSEPH M. KNAP,	WILLIAM H. BURR,	T. GUILFORD SMITH,
HORACE SEE,	JOHN THOMSON,	ROBERT B. STANTON,
WM. BARCLAY PARSONS,	ROBERT CARTWRIGHT,	AUGUSTUS MORDECAI,
F. S. CURTIS,	DESMOND FITZGERALD,	DANIEL BONTECOU,
JOHN R. FREEMAN.	HENRY D. WHITCOMB.	CHARLES WARREN HUNT.

Special Committees.

ON UNIFORM STANDARD TIME:—Sandford Fleming, Charles Paine, Theodore N. Ely, J. M. Toucey, T. Egleston.

ON ANALYSIS OF IRON AND STEEL:—Sub-Committee of the American Society of Civil Engineers (of the International Committee on Standards for the Analysis of Iron and Steel, of which Prof. J. W. Langley is Chairman)—Charles B. Dudley, William Metcalf, Thomas Rodd, A. E. Hunt.

ON UNITS OF MEASUREMENT:—George M. Bond, William M. Black, R. E. McMath, Charles B. Dudley, Alexander C. Humphreys.

The rooms of the Society are open from 9 to 17 o'clock each business day, except Saturday (when they are closed at 15 o'clock), and at other times on application to the Janitor.

HOUSE OF THE SOCIETY—127 EAST TWENTY-THIRD STREET, NEW YORK.

Vol. XXII. SEPTEMBER, 1896. No. 7.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS.

CONTENTS:

MINUTES OF MEETINGS.

OF THE SOCIETY.

September 2d, 1896.—The meeting was called to order at 20.15 o'clock, President Thomas Curtis Clarke in the chair; Charles Warren Hunt, Secretary, and present, also, 50 members and 9 guests.

The minutes of the meetings of June 3d, 1896, and of the 28th Annual Convention were adopted as printed in *Proceedings* for August, 1896.

A paper entitled "The Suspension of Solids in Flowing Water" was presented in abstract by Elon Huntington Hooker, Ph.D., and discussed by Messrs. T. C. Clarke, L. L. Buck, Foster Crowell, W. R. Hutton, C. J. Bates, and the author.

Ballots were canvassed and the following candidates declared elected:

As Members.

James Murray Africa, Huntingdon, Pa.
James Richard Bell, Calcutta, India.
Edwin Jay Nichols, Texarkana, Tex.
George Browne Post, New York City.
Charles Henry Snow, New York City.
Charles Oscar Vandevanter, Baltimore, Md.
Montgomery Waddell, New York City.

As Associate Members.

Ricardo Manuel Arango, Panama, Republic of Colombia.
Louis Edwin Hawes, Boston, Mass.
Walter Arthur Hill, Merced, Cal.
Albert Lincoln Johnson, St. Louis, Mo.
Perry Lawton, Quincy, Mass.
Charles Hedges McKinstry, Newport, R. I.

The Secretary announced the election by the Board of Direction on September 1st, 1896, of the following candidates:

As Associate.

Melville Douglas Chapman, New York City.

As Junior.

Frederic Appleton Wallace, Lawrence, Mass.

The Secretary announced the deaths of the following Members:

Job Abbott, elected Member April 1st, 1891; died August 18th, 1896.

Max Joseph Becker, elected Member August 7th, 1872; President of the Society from January 16th, 1889, to January 15th, 1890; died August 23d, 1896.

Louis Provost Evans, elected Member September 3d, 1884; died August 19th, 1896.

John Houston, elected Member May 6th, 1868; died August 30th, 1896.

Adjourned.

September 16th, 1896.—The meeting was called to order at 20.20 o'clock, President Thomas Curtis Clarke in the chair; Charles Warren Hunt, Secretary, and present, also, 71 members and 8 visitors.

A paper entitled "The New Water-Works of Havana, Cuba," was presented by E. Sherman Gould, M. Am. Soc. C. E. Correspondence on the paper from Emile Low, M. Am. Soc. C. E., was read by the Secretary, and the subject was discussed by Messrs. T. C. Clarke, E. E. Russell Tratman, James Owen, E. J. Chibas, E. Wegmann, J. F. O'Rourke, and the author.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

September 1st, 1896.—Five members present.

Messrs. William G. Curtis, Alfred P. Boller and Thomas W. Symons were appointed a Board of Censors to award the Norman Medal for 1896.

Messrs. H. A. Carson and John F. Wallace were appointed to serve with the Secretary as a Committee to award the Rowland Prize for 1896.

Messrs. William Metcalf, Samuel Rea and Thomas H. Johnson were appointed a committee to prepare a memoir of the late Max J. Beckér, Past-President.

The following resolutions were adopted, and the Secretary was instructed to have them properly engrossed and forwarded.

Whereas, the Board of Direction of the American Society of Civil Engineers desires to give expression to the appreciation of the Society for the kindness with which its members were received on the occasion of the Twenty-eighth Annual Convention; be it therefore

Resolved, that the thanks of the Society are hereby tendered to the local committee in charge of the arrangements for the Twenty-eighth Annual Convention, in recognition of the efficient manner in which the programme in all its details was planned and executed.

Whereas, the Board of Direction of the American Society of Civil Engineers desires to give expression to the appreciation of the Society for the kindness with which its members were received on the occasion of the Twenty-eighth Annual Convention; be it therefore

Resolved, that the thanks of the Society are hereby tendered to the Technical Society of the Pacific Coast for placing its rooms at the disposal of members attending the Convention and its cordial participation in their entertainment.

Whereas, the Board of Direction of the American Society of Civil Engineers desires to give expression to the appreciation of the Society

for the kindness with which its members were received on the occasion of the Twenty-eighth Annual Convention; be it therefore

Resolved, that the thanks of the Society are hereby tendered to the Southern Pacific Company for the special transportation placed at the disposal of the members and guests of the Society in attendance at the Twenty-eighth Annual Convention held in San Francisco June 29th–July 4th, 1896, which added so largely to their convenience and pleasure.

Whereas, the Board of Direction of the American Society of Civil Engineers desires to give expression to the appreciation of the Society for the kindness with which its members were received on the occasion of the Twenty-eighth Annual Convention ; be it therefore

Resolved, that the thanks of the Society are hereby tendered to The Spring Valley Water Company for the charming entertainment tendered to its members and guests on the occasion of their visit to the reservoir of that Company on July 2d, 1896.

Whereas, the Board of Direction of the American Society of Civil Engineers desires to give expression to the appreciation of the Society for the kindness with which its members were received on the occasion of the Twenty-eighth Annual Convention ; be it therefore

Resolved, that the thanks of the Society are hereby tendered to the Hon. Adolph Sutro, Mayor of San Francisco, for the pleasant entertainment tendered to the members of the Society on July 1st, 1896.

Whereas, the Board of Direction of the American Society of Civil Engineers desires to give expression to the appreciation of the Society for the kindness with which its members were received on the occasion of the Twenty-eighth Annual Convention; be it therefore

Resolved, that the thanks of the Society are hereby tendered to William H. Kennedy, Chief Engineer, and to the Oregon Railway and Navigation Company, for the special train placed at the disposal of members of the Society on July 6th, 1896, for an excursion between Portland and the Cascade Locks.

Whereas, The Board of Direction of the American Society of Civil Engineers desires to give expression to the appreciation of the Society for the kindness with which its members were received on the occasion of the Twenty-eighth Annual Convention; be it therefore

Resolved, that the thanks of the Society are hereby tendered to F. I. Fuller, Esq., General Manager, and to the Portland Traction Company, for courtesies extended to members of the Society passing through Portland, Oregon, on the return from the Convention July 6th, 1896.

One candidate was elected as an Associate and one as a Junior.

Applications were considered and other routine business transacted.

Adjourned.

ANNOUNCEMENTS.

MEETINGS.

Wednesday, October 7th, 1896, at 20 o'clock, a regular meeting of the Society will be held, at which a paper by W. A. Rogers, Jun. Am. Soc. C. E., entitled "The Reconstruction of Grand River Bridge" will be presented. This paper was printed in *Proceedings* for August, 1896, already published.

Wednesday, October 21st, 1896, at 20 o'clock, a regular meeting of the Society will be held. The paper to be presented is by George S. Morison, Past-President Am. Soc. C. E., and is entitled "Suspension Bridges—A Study." It is printed elsewhere in this number of *Proceedings.*

Wednesday, November 4th, 1896, at 20 o'clock, a regular meeting of the Society will be held, at which a paper by A. H. Sabin, Assoc. M. Am. Soc. C. E., entitled "Experiments on the Protection of Steel and Aluminum Exposed to Sea Water" will be presented. The paper is printed in this number of *Proceedings.*

Correspondence on these papers is invited from those who cannot be present at the meetings, and may be sent to the Secretary by mail. If received in time, such correspondence will be presented to the Society at the meeting at which the paper discussed is read.

DISCUSSIONS.

Discussion on the paper by Elon Huntington Hooker, Ph.D., "The Suspension of Solids in Flowing Water," printed in *Proceedings* for August, 1896, and presented at the meeting of September 2d, will be closed October 15th.

Discussion on the paper entitled "The New Water-Works of Havana, Cuba," by E. Sherman Gould, M. Am. Soc. C. E., presented at the meeting of September 16th and printed in *Proceedings* for August, 1896, will be closed November 1st.

Discussion on the paper by W. A. Rogers, Jun. Am. Soc. C. E., entitled "The Reconstruction of Grand River Bridge," which was printed in *Proceedings* for August and will be presented at the meeting of October 7th, will be closed November 16th.

Discussion on the paper by George S. Morison, Past-President Am. Soc. C. E., entitled "Suspension Bridges—A Study," which will be presented at the meeting of October 21st and is printed in this number of *Proceedings,* will be closed December 1st.

Discussion on the paper by A. H. Sabin, Assoc. M. Am. Soc. C. E., entitled "Experiments on the Protection of Steel and Aluminum Exposed to Sea Water," which will be presented at the meeting of November 4th and is printed in this number of *Proceedings,* will be closed December 15th.

MEMOIRS OF DECEASED MEMBERS.

NOTE.—Memoirs will hereafter be reproduced in the Volumes of *Transactions*. Any information which will amplify the records as here printed, or correct any errors, should be forwarded to the Secretary prior to the final publication.

JOHN ALLSTON WILSON, M. Am. Soc. C. E.*

DIED JANUARY 19TH, 1896.

John Allston Wilson was born at Phœnixville, Chester County, Pa., April 24th, 1837. He was the eldest son of W. Hasell Wilson, Hon. M. Am. Soc. C. E., a native of Charleston, S. C., an eminent railroad engineer, and Jane Miller Wilson, both of whom are still living.

Mr. Wilson came of distinguished ancestry. He was the fifth in his generation to follow the profession of engineering. The name Allston was that of his great grandmother, who was the daughter of Capt. William Allston of Marion's brigade during the Revolutionary War, and a half-sister of Washington Allston, painter and poet. She was the wife of William Hasell Gibbes, a lineal descendant of Robert Gibbes, who was Chief Justice of South Carolina in 1708 and Governor in 1710-12.

John A. Wilson received his early education at private schools, and at the age of sixteen entered the Rensselaer Polytechnic Institute of Troy, N. Y., graduating with the degree of C. E. in July, 1856. In the early part of the year 1857 he was appointed topographer under Mr. John C. Trautwine on surveys in Central America for the Honduras Interoceanic Railway, on which work he continued until the return of the party to the United States in the summer of 1858. He then entered the service of the Pennsylvania Railroad Company as Assistant Engineer, and was engaged on work on the main line of that road. In 1860 he was promoted to the position of Principal Assistant Engineer, and until 1864 was engaged in the construction of railroad shops, bridges and branch railroads in the vicinity of Philadelphia. In addition to this, from 1861 to 1864 he was Chief Engineer of the Junction Railroad, connecting the Pennsylvania, the Philadelphia, Wilmington and Baltimore, and the Philadelphia and Reading Railroads, a piece of work involving varied and heavy construction. He also made the location for the Connecting Railway between the Pennsylvania Railroad and the Philadelphia and Trenton Railroad.

In 1863 Mr. Wilson served in the defence of his country as aide on the staff of General D. N. Couch, with the official rank of Captain. General Couch was then in command of the Department of the Susquehanna, and Captain Wilson had charge of the construction of fortifications in the vicinity of Harrisburg, Pa.

From 1864 until 1868 he occupied the position of Chief Engineer for the Pennsylvania Railroad Company, lessee of the Philadelphia and Erie Railroad, with headquarters at Williamsport, Pa.

* Memoir prepared by Jos. M. Wilson, M Am. Soc. C. E.

From 1868 to 1870 he was Chief Engineer of Maintenance of Way on the main line of the Pennsylvania Railroad, with residence at Altoona. During the period from 1870 to 1875 he made the location and superintended the construction of the Low Grade Division of the Allegheny Valley Railroad between Driftwood on the Philadelphia and Erie Railroad and Red Bank on the Allegheny River. At the same time he was also Chief Engineer of the Morrison's Cove Railroad, a branch of the main line of the Pennsylvania Railroad.

In January, 1876, the firm of Wilson Brothers & Company, Civil Engineers, Architects and Consulting Engineers, was organized, in which he was the senior member up to the time of his death. This firm has designed and had charge of the construction of many important structures, one of their recent great buildings being the Philadelphia and Reading Terminal Station at Philadelphia.*

One of the provisions of this firm allowed any member to hold an official position in his individual name, with the benefit of consultation and advice from the other members, all compensation being reported to and paid into the firm, and all such professional work being considered as part of its operations. Under this provision John A. Wilson acted personally in many important works as Chief or Consulting Engineer. Among these may be mentioned: Chief Engineer of the Bloomsburg and Sullivan Railroad, the North and West Branch Railroad, the Staten Island Rapid Transit Railroad, the Bellefonte and Buffalo Run Railroad, the Nittany Valley and Southwestern Railroad, the Columbia and Sullivan County Railroad, the Philadelphia Belt Line Railroad and the Philadelphia and Reading Terminal Railroad; Consulting Engineer of the Philadelphia and Reading Railroad for the Pennsylvania Avenue Subway, etc., etc.; also as Expert Engineer or witness for a large amount of railroad and similar public work, including many cases in litigation, such as railroad crossings, etc. Mr. Wilson displayed remarkable ability in matters connected with railroad law, making him extremely valuable as an expert adviser or witness in such cases. In some instances he worked up the whole plan of procedure for a case, and on an occasion not long before his death, when he rendered an opinion to a prominent lawyer, he was complimented by a letter from him, in which he said, "Your knowledge of the law on this subject should warrant your being made an LL.D."

In addition to his membership in this Society, dating from June 7th, 1876, Mr. Wilson was also a member of the American Institute of Mining Engineers, the Franklin Institute, the Historical Society of Pennsylvania, the Philadelphia Art Club and the St. Andrew's Society of Philadelphia. He was a vestryman and communicant of St. Andrew's Protestant Episcopal Church, West Philadelphia. He leaves a wife, four daughters and two sons.

*See *Transactions*, Vol. xxxiv, p. 115.

JOB ABBOTT, M. Am. Soc. C. E.*

Died August 18th, 1896.

Job Abbott was born at Andover, Mass., August 23d, 1845. He attended the district schools and Phillips Academy before going to Harvard, where he studied engineering in the Lawrence Scientific School. After graduating in 1864, he was connected for a time with the Manchester Locomotive Works, but his active engineering work began when he was appointed Assistant Engineer on the Glen Cove branch of the Long Island Railroad. This engagement was a short one, and on its termination he went to the Pittsburg, Ft. Wayne and Chicago Railway in a similar capacity. While on this line he became interested in the city of Canton, O., a large part of which he laid out, and there he had an office as civil and mining engineer and patent expert from 1866 to 1872. During this time he studied law and was admitted to the Ohio bar.

While practicing patent law in Canton he was retained on certain matters by the Wrought Iron Bridge Company, and became so interested in these affairs that he dropped his legal practice to take up engineering again. He was Vice-President and Chief Engineer of the Wrought Iron Bridge Company from 1872 to 1880, and remained a Director until his death. During this time he built some bridges in Canada, and believing the Canadian business to have a bright future, he helped organize the Toronto Bridge Company, of which he was President and Chief Engineer from 1880 to 1884. The business in Toronto soon outgrew the capacity of the shops there, and Mr. Abbott accordingly helped to organize the Dominion Bridge Company of Montreal, of which he was President and Chief Engineer from 1884 to 1888, and President until 1890. The shops of both these companies were designed, erected and equipped under his direction, and during his connection with them he built some of the largest bridges in Canada. In 1884 and 1885 he designed and had charge of the 477-ft. steel cantilever bridge at St. John, N. B,; in 1887, a steel bridge 2 020 ft. long on the Fredericton Railway; in 1888, the superstructure of the Canadian Pacific bridge, 2 440 ft. long, at Sault Ste. Marie; in 1889, the Grand Narrows steel bridge, 1 715 ft. long, on the Dominion Government Railway in Cape Breton, N. S. In 1886 and 1887 he also had charge of building the superstructure of the Lachine Bridge, 3 660 ft. long, over the St. Lawrence River on the Canadian Pacific line.

In 1889 he found he was working too hard, and gave up his Montreal office in order to remove to New York, where he established an office as consulting engineer, which he maintained until April, 1896.

* Memoir prepared from papers on file in the House of the Society.

In 1889 and 1890 he designed and had charge of the Ohio River Bridge at Wheeling, W. Va., and was appointed Chief Engineer of the Wheeling Bridge and Terminal Railway Company. The work done by this company was very heavy, the bridge alone being a double-track structure 2 097 ft. long with a 525-ft. channel span.

After the completion of the Wheeling works, Mr. Abbott was retained as Consulting Engineer for the Bangor and Aroostook Railroad in Maine, the longest line built in New England since the Central Massachusetts was finished. While engaged in Maine in work for this road, he was taken ill but kept at his labors for about a year, when he went to Andover for health and rest. He was too late, however, and after a trying sickness died August 18th, leaving a widow.

Mr. Abbott was elected a Member of the American Society of Civil Engineers, April 1st, 1891.

NORMAN JAMES NICHOLS, M. Am. Soc. C. E.*

DIED APRIL 8TH, 1896.

Norman James Nichols was born in Essex, Vt., December 3d, 1835. He graduated from the Chittenden County Institute at that place in 1858, having taken a course in engineering, and intended to go West immediately to engage in railroad work. These plans had to be abandoned, however, and until 1862, he was engaged as carpenter and building contractor in Essex and neighboring towns. In August, 1862, he enlisted with the Second Vermont infantry and served in many severe engagements, being wounded at the Wilderness. In May, 1865, he was honorably discharged, and began work again as a contractor for buildings and highway bridges in Essex. He followed this business for about eight years, with occasional intermissions during which he was engaged as draftsman or superintendent in manufacturing establishments.

In the winter of 1873-74 Mr. Nichols moved to Worcester, Mass., and became associated with the firm of Buttrick & Wheeler, with whom he remained for three years. This firm had a general engineering practice at that time, and was engaged in laying out the sewerage, sewage disposal and water systems for the large State Lunatic Asylum in Worcester; surveys for extensions of the Worcester and Shrewsbury Railroad; the location of the Connecticut Valley Railroad, a narrow-gauge line from New Haven, Conn., to Turners Falls, Mass., and general city surveying. In 1878, Mr. Nichols was in charge of the construction of a water-power dam at Cherry Valley, Mass., to replace a structure destroyed by the Lynde Brook Reservoir disaster, which forms the subject of a report in *Transactions*, Volume V, page 244.

In February, 1879, Mr. Nichols went to the Republic of Colombia to take part under Daniel M. Wheeler in the surveys and construction of the Magdalena Railroad, about 30 miles long, connecting the navigable reaches of the Lower and Upper Magdalena River around the falls at Honda. In about a year the company engaged in the work failed, and he returned to the United States. In July, 1881, he was engaged by F. J. Cisneros, M. Am. Soc. C. E., to take the place of an engineer retiring from the staff working on the Antioquia Railroad, a 125-mile line from Puerto Berrio to Medellin, and was soon appointed Chief Enggineer of that undertaking. From April, 1882, to May, 1886, he was Chief Engineer of the La Dorada Railroad, and afterward, up to the time of his death on April 8th, 1896, was engaged in general engineering and mining work in the vicinity of Honda, Republic of Colombia.

Mr. Nichols was elected a Member of the American Society of Civil Engineers on December 5th, 1888.

* Memoir prepared from papers on file in the House of the Society.

JAMES HUGH STANWOOD, Assoc. M. Am. Soc. C. E.*

Died May 24th, 1896.

James Hugh Stanwood, who became an Associate Member of this Society October 3d, 1894, was born July 17th, 1860, at Brunswick, Me. His earlier education was received in the public schools of Portland. In 1879 he entered the office of Edward C. Jordan, M. Am. Soc. C. E., at Portland, and for about a year and a half was engaged in general land surveying. He afterward served on the survey for a railroad between North Bridgeton and Saccarappa, Me., and as assistant in the office of the City Engineer of Portland, and in the spring of 1881 went into the employ of the Maine Central Railroad Company as leveler and transitman.

Although in 1883 he entered the Massachusetts Institute of Technology as a student, and continued there for four years, he was still engaged during his summer vacations upon engineering work on the Maine Central Railroad. Graduating in 1887, he went to the Philadelphia Bridge Works as assistant to the designing engineer, and somewhat more than a year later returned to the Institute of Technology as Assistant in the Department of Civil Engineering. He afterward became Instructor, and continued in active service at the Institute, in charge of the drawing-room work in bridge design, until within a few months of his death, being compelled finally to give way before the inroads of Bright's disease.

He was enthusiastic in his attachment to the profession of civil engineering, and was not infrequently a contributor to its periodicals. He collected many specimens illustrating the rusting of iron and steel in exposed structures, such as bridges, made a careful study of the matter, and in 1895 presented a discussion on the subject before this Society. He also devised simple formulas to accord with the experiments upon the strength of wooden posts, which appeared in the *Railroad Gazette* in 1892 and 1894 and have been well received by engineers.

Mr. Stanwood was characterized by great faithfulness to all the details of his duties, and by an abounding fund of good nature which, combined with a frank and generous spirit, won for him many friends and the enduring regard of all his students. He died May 24th, 1896, in his thirty-sixth year, leaving a widow and three children.

* Memoir prepared by Dwight Porter, M. Am. Soc. C. E.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

			Date of Membership.
AFRICA, JAMES MURRAY	Huntingdon, Pa.		Sept. 2, 1896
SNOW, CHARLES HENRY	Univ. of the City of New York, Morris Heights, New York City	Assoc. M. M.	Feb. 1, 1893 Sept. 2, 1896
WADDELL, MONTGOMERY	72 Trinity Place, New York City	Jun. M.	Sept. 1, 1886 Sept. 2, 1896

ASSOCIATE MEMBERS.

DEANS, CHARLES HERBERT	Care of Sooysmith & Co., Mills Bldg., New York City	Jun. Assoc. M.	Dec. 3, 1890 May 6, 1896
GOODNOUGH, XANTHUS HENRY	State House, Boston, Mass.		May 6, 1896
TAIT, JOHN GEORGE	Care of Engr.'s Dept., New York State Canals, Stillwater, N. Y.		May 6, 1896

ASSOCIATE.

CHAPMAN, MELLVILLE DOUGLAS	253 Broadway, New York City.	Sept. 1, 1896

JUNIORS.

GIFFORD, LESTER ROBINSON	Capital Hotel, Johnstown, Pa.	Mar. 3, 1896
SMITH, JOHN TURNER	Riogrande, Texas	Mar. 31, 1896

CHANGES AND CORRECTIONS.

MEMBERS.

BAKER, HOLLAND WILLIAMS	913 Security Building, St. Louis, Mo.
BRODHEAD, CALVIN E.	Easton, Pa.
CORNELL, GEORGE B.	31 Sands St., Brooklyn, N. Y.
EARLEY, JOHN E.	Calle Ortega 28, Cuarto 4, Mexico, Mexico.
FREEMAN, JOHN RIPLEY	102 Waterman St., Providence, R. I.
GOULD, EDWARD SHERMAN	Scranton Gas and Water Co., Scranton, Pa.
HISLOP, JOHN	Greenriver, Utah.
MORLEY, FRED.	La Fayette, Ind.
ROBERTS, NATHANIEL	31 Broadway, New York City; 7 Oak St., Jersey City, N. J.; Residence, 74 Ocean Ave., Jersey City Heights, N. J.

SIMS, ALFRED VARLEY..........Iowa City, Iowa.
SMITH, S. HARRISON............Care of J. D. Schuyler, 415 W. Washington St., Los Angeles, Cal.
WALTON, CHARLES WALLACE ....Wisner, La.
WRIGHT, AUGUSTINE WASHINGTON. 1301 Fisher Bldg., Chicago, Ill.
YATES, PRESTON KING ....Reservoir No. 5, Metropolitan Water Supply, Marlboro', Mass.
YONGE, SAMUEL H..............Div. Engr. to Missouri River Commission, Government Bldg., Council Bluffs, Iowa.

ASSOCIATE MEMBERS.

CREUZBAUR, R. WALTER........520 Nostrand Ave., Brooklyn, N. Y.
HARDY, HARRY ....Green's Hotel, Havelock Road, Hastings, Sussex, England.
HYDE, ABRAHAM L. ....New England Bldg., Cleveland, O.
MCMEEKIN, CHARLES WILLIAM..Chf. Engr. Iowa Central Ry. Co., Marshalltown, Iowa.
MEEM, JAMES COWAN...........The Arlington, 64 Montague St., Brooklyn, N. Y.
RAPP, J. V. B. ....66 West 3d St., New York City.
WOERMANN, JOHN WILLIAM .....503 Fifth Ave., Sterling, Ill.

JUNIORS.

ADEY, WILLIAM H..............Dongan Hills, Staten Island, N. Y.
BELL, ALFRED C...............101-19th St., Milwaukee, Wis.
CHRISTY, GEORGE L. ....447 West 23d St., New York City.
FORD, WILLIAM H..............Olean House, Olean, N. Y.
MASON, GEORGE COTNER ....132 Nassau St., New York City.
MILLARD, CURTISS . ...Chf. Engr. St. L. C. & St. P. R. R., 212 North 5th St., Springfield, Ill.
MONSARRAT, NICHOLAS D. ......515 E. Broad St., Columbus, Ohio.
SHERMAN, CHARLES W..........35 Langdon St., Cambridge, Mass.
SPEIDEL, HUGO S. ....66 West 3d St., New York City.
TABER, GEORGE AYMAR.........74 West 82d St., New York City.
TAPPAN, ROGER................Cor. Mt. Vernon St. and Highland Ave., Haverhill, Mass.
WALLS, WALTER S. ....9 Orange St., Chelsea, Mass.

DEATHS.

ABBOTT, JOB...................Elected Member April 1st, 1891; died August 18th, 1896.
BECKER, MAX JOSEPH...........Elected Member August 7th, 1872; died August 23d, 1896.
EVANS, LOUIS PROVOST ....Elected Member September 3d, 1884; died August 19th, 1896.
HOUSTON, JOHN ....Elected Member May 6th, 1868; died August 30th, 1896.

ADDITIONS TO

LIBRARY AND MUSEUM.

From Miguel de Teive e Argollo, Bahia, Brazil:
Informação sobre o Arrendamento das Estradas de Ferro.

From Austrian Engineers' and Architects' Association, Vienna, Aus.:
Schäden an Dampfkesseln, Heft II, Schäden an Stabilkesseln.

From Board of Public Works, Duluth, Minn.:
Ninth Annual Report for the year ending February 29th, 1896.

From Boston Public Library, Boston, Mass.:
Monthly Bulletin of Books added August, September, 1896.

From Elmer L. Corthell, New York, N. Y.:
Some Notes, Physical and Commercial upon the Delta of the Mississippi River.

From Robt. A. Cummings, Philadelphia, Pa.:
Specimen of "Torregia Taxifolia," or "Stinking Cedar," from Liberty Co., Fla., after 38 years' exposure.

From T. Chalkley Hatton, Wilmington, Del.:
Ninth Annual Statement of the Board of Directors of the Street and Sewer Department of Wilmington, Delaware, for the fiscal year ending January 31st, 1896.

From F. V. Hinckley, Topeka, Kans.:
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1896. SEPTEMBER. No. 7.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CONTENTS:

SUSPENSION BRIDGES—A STUDY.

By GEORGE S. MORISON, Past President Am. Soc. C. E.

TO BE PRESENTED OCTOBER 21ST, 1896.

Fifty years ago the suspension bridge was regarded as the one class of structure adapted to spans of unusual length. Highway suspension bridges were built in almost all parts of the world; several railroad suspension bridges were proposed, and the one actually built across the Niagara River has done service for nearly forty years. Fifty years ago metallic bridge construction was in its infancy, and anything beyond the limit which could well be built of wood was considered an exceptional span. Athough there were a few striking exceptions, 200 feet was practically the limit of wooden truss bridge spans.

The introduction of iron bridges changed these conditions, and a 400-ft. iron span was as readily built as a 200-ft. Howe truss. The

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

first 400-ft. span in America was constructed by Albert Fink, Past-President Am. Soc. C. E., in the bridge across the Ohio River at Louisville, Ky., where it is still in use. The cheapening of the price of iron, the increased capacity of rolling mills, and the new methods of making steel, have rendered it an easier task to build a truss of 600 ft. span now than it was to build a 400-ft. span then. The result of this development has been that trusses have superseded suspension bridges, and where a suspension bridge would have been built forty years ago a steel truss is built now.

Furthermore, the old suspension bridges were highway bridges, and highway traffic does not enter upon a bridge as a concentrated load, while it is generally light in proportion to the dead weight of the bridge. Important modern bridges are generally railroad bridges, and the suspension bridge has not been considered stiff enough to serve this purpose, this want of stiffness being largely due to the fact that on a single-track railroad bridge the whole moving load comes on as a concentrated load, and that on railroad bridges of moderate span the moving load is large in proportion to the dead load.

No important suspension bridge has been built since the East River Bridge, the design of which was shaped by the elder Roebling before his death in 1869. During this time great advances have been made in all other forms of bridge construction. While it is admitted that there is no field for suspension bridges of the dimensions of which they were formerly built, a new field is opening in structures of enormous size, bridges that would bear the same relation to a 600-ft. steel truss that the 1 000-ft. suspension span at Cincinnati bore to the 200-ft. truss spans built about the same time in the same neighborhood across the Great Miami.

If, at the present day, an 800-ft. span is to be built, a truss on the beam or cantilever principle would be used, but a 2 000 or 3 000-ft. span would be a case for a suspension bridge. Two things must be remembered. In a suspension bridge of any such enormous size the dead weight would be large in proportion to the live load, and the distortion due to the passage of trains would be comparatively small. Such a bridge would be built for two or more railroad tracks, its length would be much greater than that of a single train, and the condition under which a concentrated maximum load would advance as a whole, upon the bridge would be rare. In the manner of the passage of loads

such a bridge would resemble a highway bridge more than a short-span railroad bridge.

Before, however, a suspension bridge is built which will bear the same relation to the modern steel truss that the old suspension bridge did to the wooden truss, the same advance in details must be made in suspension bridges that has been made in truss bridges. If such a bridge is to be built now, the designer must concentrate in the work of a single design all the improvements corresponding to those which truss bridge builders have spent many years in developing.

This paper is submitted with a view to opening the way for improvement and to show that a great suspension bridge, which would be well adapted to railroad service, would involve no insurmountable difficulties of construction.

The method of demonstration and illustration which has been adopted is the explanation of the design of a suspension bridge of unusual dimensions and capacity. The size selected for this design would give a clear opening of about 3 000 ft., this corresponding to the dimensions proposed for the North River at New York. The plan discussed is simply a general plan, but as such a discussion to be valuable must be accompanied by estimates, the depth to rock at the sites of the towers has been assumed to be 140 ft. below mean high water; this corresponds to the depths which borings have found opposite the foot of Seventieth Street. It has been assumed also that the anchorages would be built on rock, and elevations have been assumed for these anchorages. These elevations correspond with reasonable accuracy to the position of the bluffs on the west side of the river opposite Seventieth Street, and are probably not very different from the position of the rock on the east side at the same location, but it is not likely that a structure located there would be of the symmetrical character which is now described. The design gives a clear headroom of 150 ft. at all stages of water.

While these conditions correspond more closely to the location at the foot of Seventieth Street than to any other place, this paper is intended as a study of suspension bridges and not as an approval of any particular location. The location at Seventieth Street undoubtedly has great advantages, especially in the matter of anchorages. A location below Thirty-fourth Street has also very great advantages, particularly in the matter of convenience to existing business centers.

It must be observed that the distinctive feature of a suspension bridge lies in the fact that it has no compression member. The weight is carried by cables stretched from tower to tower, which are secured by heavy anchorages at each end. The strains in the cables tend to overturn the anchorages, and any motion of the anchorages disturbs the entire structure; a slight settlement in the towers might not do much harm; any motion in the anchorages is felt through the entire bridge. In this respect the conditions of a suspension bridge are the opposite of those of a cantilever bridge. Any settlement in the towers of a cantilever bridge is exaggerated at the ends of the cantilevers, while the anchorages are usually of such character that they can easily be adjusted. It is therefore of the utmost importance that the anchorages of a suspension bridge should have foundations which will not yield and which can be put in at reasonable cost. These conditions are assumed in the estimates in this paper. A study of the paper, however, will show that the form of anchorage proposed admits of great latitude in use, as the inclination of the backstays becomes independent of the inclination of the main cables, and the anchorage for one pair of cables may be placed much farther back from the tower than the other pair. This might present great advantages if it became necessary to locate anchorages in a portion of the city already built up.

The capacity of the bridge designed has been reached in a back-handed manner. The bridge has been designed to carry a total load of 25 tons or 50 000 lbs. per lineal foot. The design has then been developed and the dead weight calculated, and the result is a balance for the live load of 11 000 lbs. per foot over the entire structure. As the width of the structure is 92 ft. between the stiffening trusses, this corresponds to about 120 lbs. per square foot of floor. If this space were to be occupied by eight railroad tracks it would amount to 1 375 lbs. per lineal foot per track, which exceeds the weight of any passenger train. It would amount in the aggregate on a length of 3 100 ft. to 34 110 000 lbs., equivalent to eight freight trains 1 400 ft. long, each weighing 3 000 lbs. per lineal foot. It is probable that the requirements of any location where a bridge of this magnitude would be considered, would be satisfied by four railroad tracks adapted to a heavy class of traffic and four rapid transit tracks to be operated by electric cars or short trains of a character which would require only a floor stiffener to secure the necessary rigidity. Therefore, in propor-

tioning the stiffening truss the variable load has been taken on the basis of 12 000 lbs. per lineal foot, corresponding to a load 3 000 lbs. per foot on each of the railroad tracks, with no provision for unequal weight on the rapid transit tracks, or to 1 500 lbs. per lineal foot on all eight of the tracks. These provisions correspond to four maximum freight trains or eight maximum passenger trains.

In one respect the design departs radically from suspension bridges hitherto built. The cables, instead of being made of straight wires, are made of ropes, and these ropes, instead of being passed over the towers and around pins in the anchorages, are socketed, both at the top of the towers and in the anchorages, all connections being made through the sockets. This modification is really the essential feature of the whole design. The objections which will be raised to it are, first, that a straight wire is both stronger and less extensible than a twisted rope made of the same wire; and second, that no socket can be made which will develop the full strength of the rope. Both of these objections are true, but a rope can be laid in such a way that the modulus of elasticity is only about 1 000 000 lbs. less than that of a straight wire, and a rope can be socketed in a way which can be absolutely depended upon to a fixed amount of strain, and the strength of the structure will then be determined, not by the strength of the wire, but the strength of the connection at the end of each rope. Furthermore, experiments have shown that ropes constructed in the manner proposed have an extremely uniform modulus of elasticity, which is the most important thing. The advantages of this system of construction are principally two; the ropes can be made in the shop, adjusted to length there, carried to the bridge site and put up in the least possible time; the wires are practically straight from one end to the other, the decided turns required over saddles and the short turns required around pins being entirely avoided. With this arrangement the objections to a strong stiff wire are removed.

Another feature which is believed to be novel is the method of holding down the ends of the stiffening truss. When one-half the span is loaded, the upward reaction at the unloaded end is equal to the downward reaction at the loaded end, so that the stiffening truss must not only be supported but anchored down. The stiffening truss of this design is made 1 000 ft. longer than the span, thus extending 500 ft. back toward the shore from each tower, while the suspenders in the

150 ft. next to each tower are omitted. The result is that the duties of the stiffening truss proper are confined to a length of 2 800 ft.; back of each tower is a span of 500 ft., from which a cantilever 150 ft. long projects to each end of the stiffening truss proper. The reactions of the stiffening truss are taken by the ends of the cantilevers, and the cantilevers are themselves anchored by the weight of the shore spans. This arrangement has the further advantage of leaving 150 ft. between the towers and end suspenders, within which the cables will adapt themselves to any changes of length and height due to temperature, loads or otherwise.

The description of the design follows the order of computation, the cables being first proportioned to carry the selected weight (50 000 lbs. per foot), the towers being proportioned to carry the cables, the foundations being proportioned to carry the towers, the anchorages designed to resist the pull of the cables, and the suspended superstructure to distribute the moving load.

General Design.

The general design is that of a stiffened suspension bridge, the cables to be of wire, the towers of steel on masonry foundations, the structure being stiffened by steel trusses suspended from the cables.

The cables are four in number, two on each side, the length of span between the theoretical intersection points on the top of the towers being 3 200 ft. and the versed sine 400 ft. To secure lateral stability, the two stiffening trusses are placed 100 ft. between centers horizontally, this affording an opening 92 ft. wide in the clear. At the middle of the span the two cables on each side are brought as close together as possible, or 4 ft. between centers, the width at the center of the span between points midway between the two cable centers being 115 ft. At the top of the towers the cables are spread apart to a distance of 28 ft., the width between the centers of the towers being 200 ft. Each inside cable has, therefore, a cradling of 30.5 ft., and each outer cable a cradling of 54.5 ft., the average cradling between 42.5 ft. The backstays are carried from the towers to the anchorages in planes which are tangent to the horizontal projection of the cradled cables, thus splaying the backstays apart between towers and anchorage. By this arrangement the towers are relieved of all transverse strain, and become, as it were, simply gin poles to

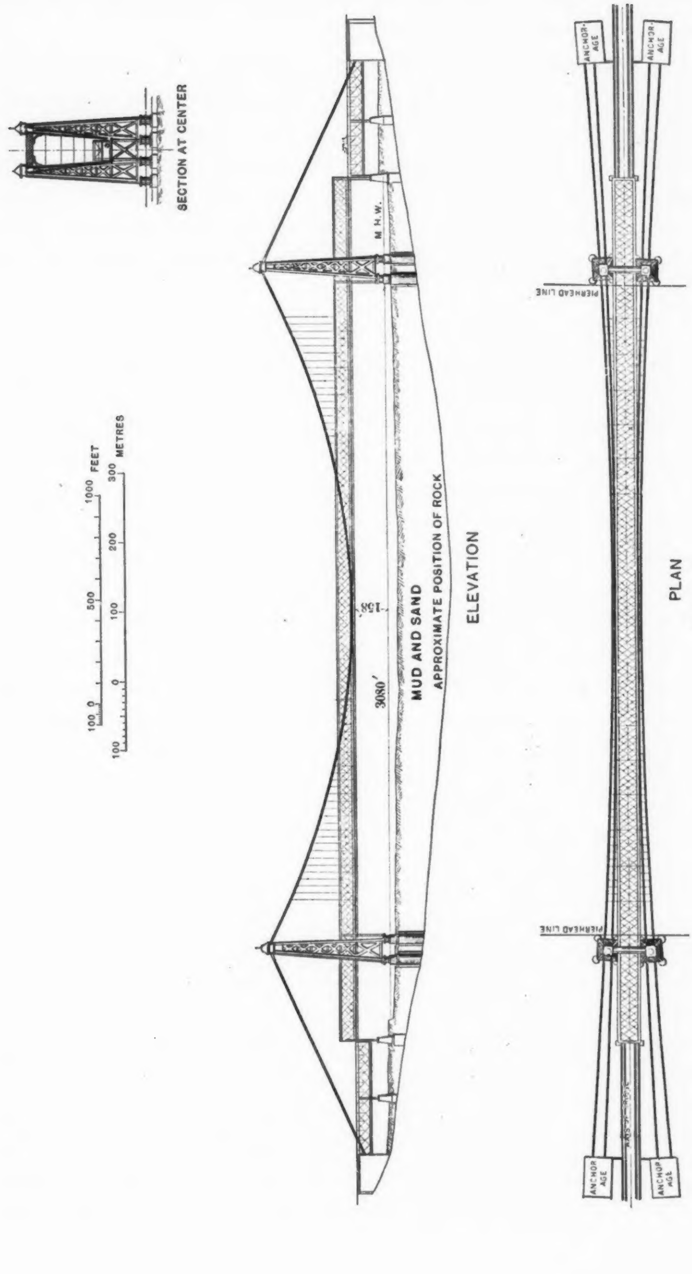

SECTION AT CENTER
1000 FEET
300 METRES
500
200
100
0
100
100
M.H.W.
158'
3080'
MUD AND SAND
APPROXIMATE POSITION OF ROCK
ELEVATION
ANCHOR-AGE
PIERHEAD LINE
PLAN

Fig. 1.

sustain the cables. The lateral stability produced by this arrangement is evident from the plan, Fig. 1.

The towers are of steel, each really consisting of two independent towers formed of four posts, 94 ft. square at the base and battered together so as to be 28 ft. square on the top, the two square towers being connected by a cross truss at the top and resting on masonry cylinders at the bottom. The exact shape and location of the half towers are determined by the direction of the cables, the sides of the two half towers not being parallel and the squares being only approximate.

It has been considered important to reduce the number of cables to four, two on each side. If the cables of the main span and the backstays are counted as separate cables, which the detail hereafter described shows them to be, there are four cables, two leading in each direction, terminating at the top of each tower, the number of cables corresponding to the number of posts, so that the weight from each cable is transferred directly to one of the four posts. This requires cables of much larger dimensions than have ever been used, but there is nothing impracticable in making cables of the required size.

The stiffening truss is 4 100 ft. long over all, divided into panels of 33 ft. 4 ins. each, supported for the central 2 800 ft. by suspenders leading from the cables, while the ends are supported on piers 4 100 ft. apart and intermediate supports are taken on rocking bents 3 100 ft. apart. The truss is continuous for its whole length of 4 100 ft., fastened to the cables at the center and free to move longitudinally at each end. It is considered of great importance to use a continuous truss, thus avoiding the difficulties and lost motion of a central hinge. The difficulties of fastening down a stiffening truss are overcome by the end supports, the end of each truss being a 500-ft. span resting on two supports, from which a 150-ft. cantilever projects towards the point where the suspenders begin. The suspended stiffening truss is only 2 800 ft. long and exerts an upward or downward reaction at the end of the 150-ft. cantilever, according to the position of the moving load; the cantilevers are anchored by the weights of the end spans. The stiffening truss is 66 ft. 8 ins. deep between the centers of gravity of the chords, this depth being adopted for reasons given hereafter; it at once secures the necessary rigidity and permits sufficient flexibility to allow a considerable por-

tion of the irregular moving load to be taken care of by the change of shape in the cables.

The general elevation, Fig. 1, shows a clearance of 158 ft. above mean high water at the center of the span at a mean temperature of 60° Fahr., when the bridge is unloaded. The extreme effects of temperature are to lower or raise the center 3.15 ft., so that the maximum clearance of the unloaded bridge at a temperature of 0° Fahr. would be 161.15 ft., and the minimum clearance at a temperature of 120° Fahr. would be 154.85 ft. A moving load of 11 000 lbs. per lineal foot over the whole span, being the amount hereafter calculated on, and using a modulus of elasticity of 27 000 000 in the cables, will cause a deflection of 3.96 ft. at the center, thus reducing the minimum possible clearance to 150.89 ft. This load is, however, excessive, and the maximum load which should be estimated in calculating clearances is 9 000 lbs. per lineal foot, which will cause a deflection of 3.24 ft., making the minimum clearance 151.61 ft. The bridge is designed with a camber of 6 ft. in the center of the span when unloaded at mean temperature; this corresponds to a camber of 9.15 ft. when unloaded at the lowest temperature and to a camber of −0.39 ft. when fully loaded at the highest temberature. The maximum camber curve corresponds to a grade of 1.18% at the ends; but this is so short that it will not affect the passage of trains.

In this design the essential difference between a great suspension bridge and a truss bridge of ordinary dimensions has been borne in mind. The truss bridge of ordinary dimensions is so nearly a rigid structure that the changes which take place in its form under passing loads have little influence on the strains in the several members, and such a bridge can be proportioned on the basis of a rigid geometrical skeleton. A long span suspension bridge necessarily changes its shape with every change of load, and changes too in such manner as to relieve local strains, every unstiffened suspension bridge having some shape of perfect equilibrium for every possible loading. These changes of shape play an important part in proportioning a suspension bridge, and so long as they are kept within limits which do not disturb convenience of operation, they are a source of strength instead of weakness. A suspension bridge must be permitted to change its shape within proper elastic limits, and this change of shape must be made the basis of calculations in proportioning the structure.

Capacity.

The bridge has been proportioned to carry a total load of 50 000 lbs. per lineal foot, which is equivalent to a stress of 40 000 000 lbs. on each of the four cables at the center of the span. The actual dead weight of the cables and suspended superstructure is about 39 000 lbs. per lineal foot, thus leaving 11 000 lbs. for moving load.

The width in the clear between trusses is 92 ft., which will provide for two double-track railroads, each occupying 26 ft., with a space 40 ft. wide between. This 40 ft. can be occupied in various ways; its width is the same as the width between the curbs of Broadway at Twenty-sixth Street; it could be used for four rapid-transit tracks either for street cars or for rolling stock of the same dimensions as that used on the elevated railroads; it could be used as a street with two sidewalks and a roadway between wide enough for four carriages to pass; it could be used for two standard gauge railroad tracks, with a broad promenade for foot passengers between, or it could be used as a driveway with a street railroad track on each side. Another possible arrangement is the construction of eight parallel railroad tracks 11 ft. between centers which is admissible on perfectly straight lines, but it is not important to decide how this bridge would be used. Enough has been said to show the capacity which would be afforded, and the weights for which it should be designed.

Cables.

The cables are the fundamental feature of the design, and will therefore be described first. The design of the cables departs radically from the features hitherto followed in suspension bridges, and provides a method of constructing suspension bridge cables, under which it is possible to do nearly all the work in the shops, and to diminish field work to a minimum.

The bridge is designed with a versed sine of 400 ft. under maximum load, this being equal to one-eighth the span. On the basis of a uniform load of 50 000 lbs. per lineal foot, or 12 500 lbs. per cable, the stress in each cable becomes 40 000 000 lbs. at the center of the span, and 40 000 000 lbs. multiplied by $\frac{\sqrt{5}}{2}$, or 44 721 360 lbs. at the ends of the span, while the vertical reaction at each end is 20 000 000 lbs.

Each cable is composed of 253 ropes of equal size arranged in the form of a hexagon with three ropes omitted from each corner; the maximum stress on each rope will therefore be 76 764 lbs. In the design, the ropes are made $2\frac{1}{8}$ ins. diameter, each rope being assumed to have a section equivalent to 3 sq. ins. of solid metal and to weigh 10 lbs. per lineal foot. The stress per square inch on these ropes, will, therefore, be 58 921 lbs., of which $\frac{39}{50}$, or 45 958 lbs., will be caused by dead load, and $\frac{11}{50}$, or 12 963 lbs., by moving load.

Each rope will be a specially laid rope formed of a single straight wire at the center, around which are grouped successive layers of helicoidal wires, so inclined that all will be of the same length, the alternate layers being inclined in opposite directions. When put under strain all wires are equally strained, except the single central wire which acts as a core. This rope bears no resemblance to the ordinary twisted rope. If not larger than No. 8, the wires of each rope can be made continuous from end to end without splicing.

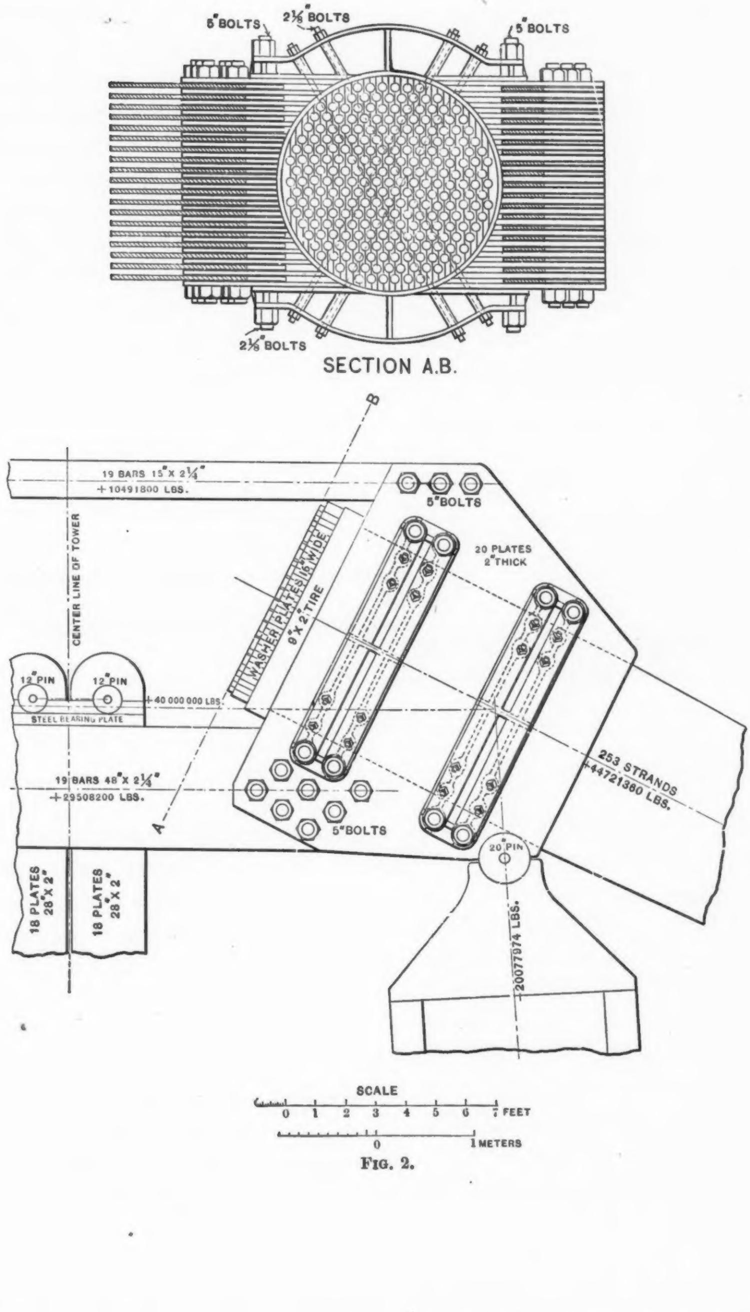
A number of sample ropes were specially prepared by the Trenton Iron Company under the direction of E. G. Spilsbury, M. Am. Soc. C. E., and these ropes were tested at the Watertown Arsenal. The results of these tests will be found in Appendix A. While these tests were of a preliminary character, and the ropes differed in some respects from those which would actually be used in a bridge, they established two important facts: First, that a laid or twisted rope could be made which will develop in the actual rope a strength of more than 180 000 lbs. per square inch of wire, and this with a wire which can be furnished at a reasonable cost; second, that a laid or twisted wire rope of this kind can be depended on in a structure to act uniformly and with a regular modulus of elasticity, the action of the different ropes tested in the latter respect being entirely satisfactory. Twelve ropes were tested in all, of which four were of straight round wires, four twisted round wires, and four twisted wires of the special forms used in a locked rope. The experiments showed the decided superiority of the rope of twisted round wires in all respects except one. The wires were evidently more uniformly strained in this rope than in the straight wire rope, and gave decidedly better results than the peculiar-shaped wires in the locked rope. The only respect in which the twisted rope was inferior to the straight rope was in the modulus of elasticity, which was about 25 000 000 in the

twisted rope, and 28 000 000 in the straight wire rope. The twisted rope was made with a machine already in existence, and with the twist commonly used on similar ropes. For the special use considered, it is probable that the twist could be reduced to one-half or perhaps to one-third that laid by this machine, and that the modulus of elasticity could be raised to about 27 000 000. The modulus of elasticity does not affect the strength of the structure; the only effect of a low modulus is slightly to increase the deflection. In none of the twelve tests, involving twenty-four sockets, did a rope pull out of a socket, but in nearly every instance the fractures occurred in the outer layer of wires and inside the sockets. An examination of the sockets showed a rough shoulder, which undoubtedly had something to do with this fracture. By a modification of the interior shape of the socket, it is probable that this difficulty could be largely removed, and the strength of the ropes increased from 5 to 10 per cent.

Each rope will be fitted into a steel socket at each end 12 ins. long, the diameter of the socket to be twice the diameter of the rope. By adjusting the ropes under strain at the works, and arranging a special machine to trim the under edge of the socket after the rope is fastened into it, it is believed that the length can be so accurately fixed that no further adjustment will be required in the field. If, however, this cannot be done, the arrangement designed permits the employment of fillers under the square shoulders of the sockets, so that the ropes can be adjusted in position.

There will be four cables in the main span of the bridge. There will be four cables in the backstays on each side of the river. There will, therefore, be twelve cables in all, each of which must be fastened at each end.

The method of fastening the cables is shown in Fig. 2. Fifty feet from each end the several ropes, which are compressed compactly together in the body of the cable, begin to separate so that they are 4.9 ins. between centers at the ends, and the successive vertical sets of ropes are 4¼ ins. between centers. On the top of each tower post is placed a steel casting through which all vertical strains are transmitted, and on this casting rests a 20-in. steel pin. On this pin are set up 20 steel plates 2 ins. thick, each plate measuring 10 ft. in the direction of the axis of the cable and weighing 9 255 lbs. The several



5" BOLTS
2⅛" BOLTS
5" BOLTS
2⅛" BOLTS
SECTION A.B.
19 BARS 15" X 2¼"
+10491800 LBS.
5" BOLTS
CENTER LINE OF TOWER
20 PLATES
2" THICK
WASHER PLATES 16" WIDE
9" X 2" TIRE
12" PIN
12" PIN
+40 000 000 LBS.
STEEL BEARING PLATE
19 BARS 48" X 2¼"
+29508200 LBS.
253 STRANDS
+44721360 LBS.
5" BOLTS
20" PIN
18 PLATES 28" X 2"
18 PLATES 28" X 2"
+20077974 LBS.
SCALE
0 1 2 3 4 5 6 7 FEET
0 1 METERS

FIG. 2.

ropes of which the main cable is composed, when spread, pass between these several plates, being held in exact position by cheap cast-iron fillers between the ropes. These plates are machined to a true plane surface on the upper edges, and on these are placed a series of washer plates on which the sockets at the ends of the cables bear. These washer plates are 2¼ ins. thick by 16 ins. deep, and the divisions come in line with the centers of the ropes. Each washer plate is bored out for its whole depth on each side with half holes slightly larger than the diameter of the ropes, and for a depth of 10 ins. with half holes of the diameter of the sockets. (See Fig. 3.) Each rope therefore passes through a round hole, one-half of which is bored in each adjacent washer plate and the socket fits into an enlargement of this round hole, bearing on the annular surfaces between the large

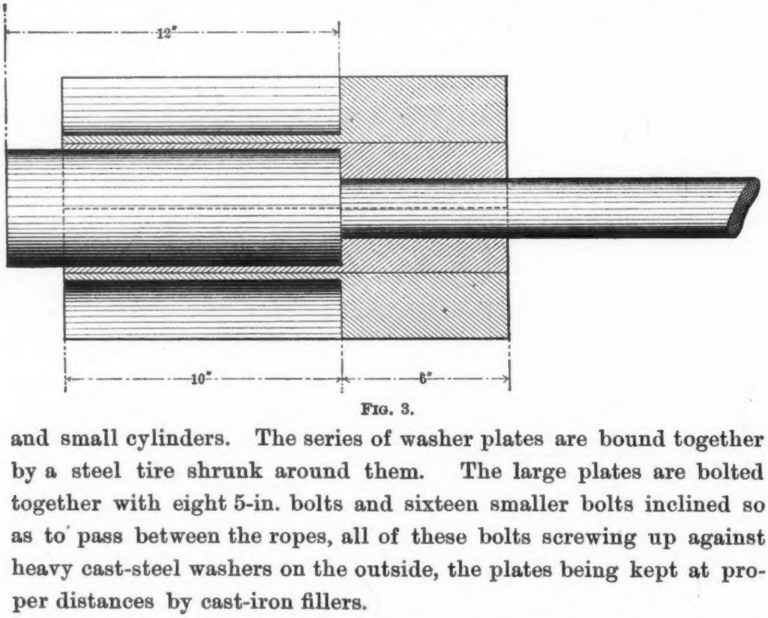


FIG. 3.

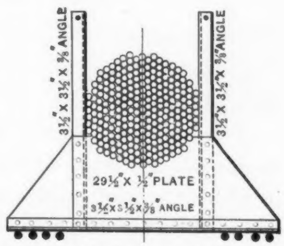
and small cylinders. The series of washer plates are bound together by a steel tire shrunk around them. The large plates are bolted together with eight 5-in. bolts and sixteen smaller bolts inclined so as to pass between the ropes, all of these bolts screwing up against heavy cast-steel washers on the outside, the plates being kept at proper distances by cast-iron fillers.

The entire strain in the cables is transmitted to the large steel plates through the washer plates which bear against them. In the large plates this strain is decomposed into a nearly vertical strain which passes through the 20-in. pin and the steel casting into the post, and a horizontal strain which is taken across the top of the tower to the corresponding backstay connection. For convenience of construc-

tion and erection this horizontal strain is divided between two tension members, the lower one consisting of nineteen bars each 48 x $2\frac{1}{4}$ ins., and the upper of the same number of bars each 15 x $2\frac{1}{4}$ ins., the strain being transmitted to the former by nine 5-in. pins, and to the latter by three 5-in. pins. The full details of this arrangement appear in Fig. 2.

To erect the cable, carrier ropes will be placed above, on which the permanent ropes will be hauled out into place. Eight auxiliary ropes, the general position of which is shown in Fig. 4, will then be run through the unoccupied spaces outside of the washer plates, and on these at suitable intervals a number of iron horses erected. These horses will serve to confine the cable. They are arranged in pairs and braced together, so that they will be stable and will afford room for men to stand and watch the laying of the ropes.

The side washers, large plates and the nineteen lower ties will be put in position, but the spaces between the plates will be open above. The first washer plate will then be put in place and the first rope unreeled and hauled across the river on the carrier ropes. As soon as it is hauled across, the sockets will be dropped into their places in the washer plates. The first three ropes having been laid in this manner, the next washer plate will be put on as well as the necessary fillers; four other ropes will then be run in the same manner and the third washer plate put on. Five ropes will then be run and the fourth washer plate laid. This process will be continued until all the ropes have been laid and all the washer plates are in position, when the washer plates will be finally consolidated by shrinking on the steel tires. The insertion of the diagonal bolts can begin whenever all the ropes below any one of these bolts are laid. The upper 5-in. bolts will be put in when the laying of the ropes is completed. When this is done the nineteen upper tie bars will be placed, bolted up, and the cables are made. By the use of the horses every rope can be put in its final position as fast as laid, and when each layer of ropes is completed men can be sent over them to make sure that they are properly laid, to paint them and prepare everything in readiness for the next layer.



HORSE ON TEMPORARY CABLES DURING ERECTION
FIG. 4.

The work is condensed as it goes on, and as soon as the last rope is laid each cable is practically complete. Various special appliances must, of course, be worked out. It may even be necessary to use fillers under the socket bearings and adjust each rope by itself. This description, however, shows the main features of the work. It is believed that at least three ropes can be laid daily, and that a cable can be completed in three working months where everything is organized and ready.

As the small tie bars at the top cannot be put in until the cable is completed, it is necessary to hold the broad lower bars so as to overcome the bending strain due to the center of these bars being below the center of horizontal strain. This is accomplished by the use of 36 bars, 28 x 2 ins. in size, which pass between the 19 bars and anchor those bars down to deep cross girders which connect the separate tower posts, as shown in Fig. 5. These vertical ties serve during erection to take out the bending strain in the lower horizontal tie, and, after erection, to bind the whole arrangement rigidly to the top of the tower.

The backstays are of the same dimensions as the main cables and connected at the top of the towers in precisely the same way, the plates to which the backstays are attached being tied to those to which the main cables are attached. In order to keep the cradled cables of precisely the same length, the outer bearings on top of the tower are lower than the inner bearings, as appears in Fig. 6.

Though the backstays are of the same dimensions as the main cables they carry no weight but themselves and run in approximately straight lines (being deflected from absolutely straight lines by their own weight) to and through the anchorages, each anchorage having two tunnels in it through which the backstays run.

At the lower end the ropes of the backstays are spread between plates in the same manner as at the top of the tower, though the details are different because of the direction in which the strains must be transferred. These details are shown in Fig. 7. The strain in the cable is divided into two equal strains, on lines making equal angles with the axis of the cable, and transferred through 26-in. pins to steel castings which bear on closely cut granite masonry, which is built into the coarser material of the anchorage. The lower pin and castings are put in position before placing the cables, but the upper

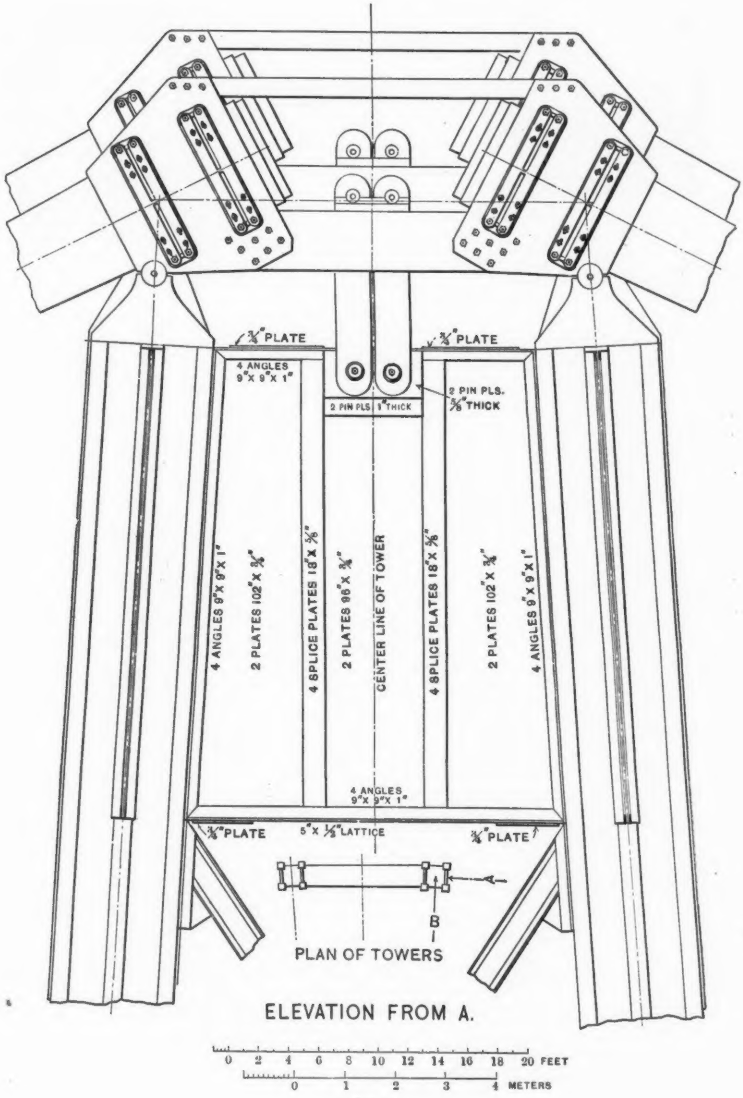

3/4" PLATE
3/4" PLATE
4 ANGLES 9" X 9" X 1"
2 PIN PLS. 5/8" THICK
2 PIN PLS 1" THICK
4 ANGLES 9" X 9" X 1"
2 PLATES 102" X 3/4"
4 SPLICE PLATES 18" X 5/8"
2 PLATES 96" X 3/4"
CENTER LINE OF TOWER
4 SPLICE PLATES 18" X 5/8"
2 PLATES 102" X 3/4"
4 ANGLES 9" X 9" X 1"
4 ANGLES 9" X 9" X 1"
3/4" PLATE
5" X 1/2" LATTICE
3/4" PLATE
A
B
PLAN OF TOWERS
ELEVATION FROM A.
0 2 4 6 8 10 12 14 16 18 20 FEET
0 1 2 3 4 METERS

FIG. 5.

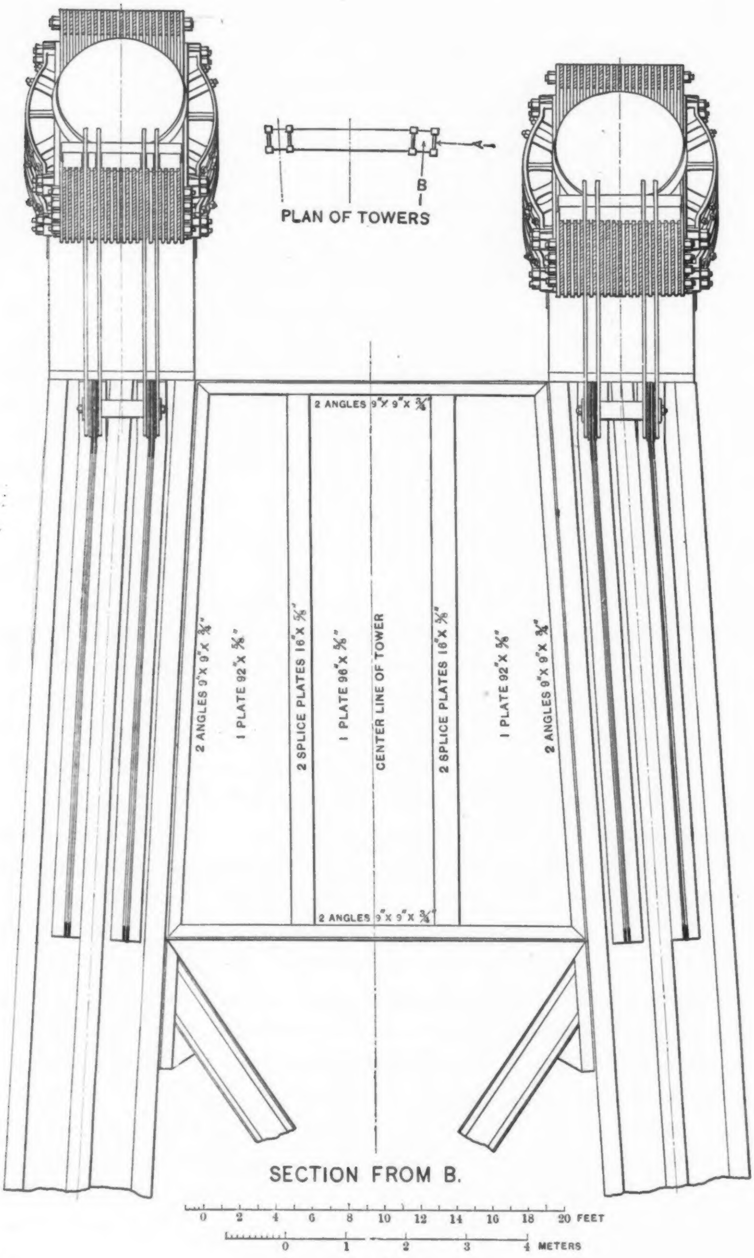

PLAN OF TOWERS
B
2 ANGLES 9"X 9"X 3/8"
2 ANGLES 9"X 9"X 3/8"
1 PLATE 92"X 5/8"
2 SPLICE PLATES 16"X 5/8"
1 PLATE 96"X 5/8"
CENTER LINE OF TOWER
2 SPLICE PLATES 16"X 5/8"
1 PLATE 92"X 5/8"
2 ANGLES 9"X 9"X 3/8"
2 ANGLES 9"X 9"X 3/8"
SECTION FROM B.
0 2 4 6 8 10 12 14 16 18 20 FEET
0 1 2 3 4 METERS

FIG. 6.

one must be omitted so as to slip the ropes between the plates. To compensate for the omission of this pin, nineteen 10 x $2\frac{1}{8}$-in. eye-bars, coupling on a 7-in. pin, pass down a hole sunk into the rock foundation of the anchorage, and are anchored at the bottom of the hole in the manner shown in Fig. 8, these eye-bars serving only a temporary purpose. When the cables are completed, the upper pins and castings are put in position, the granite masonry built up on the castings and

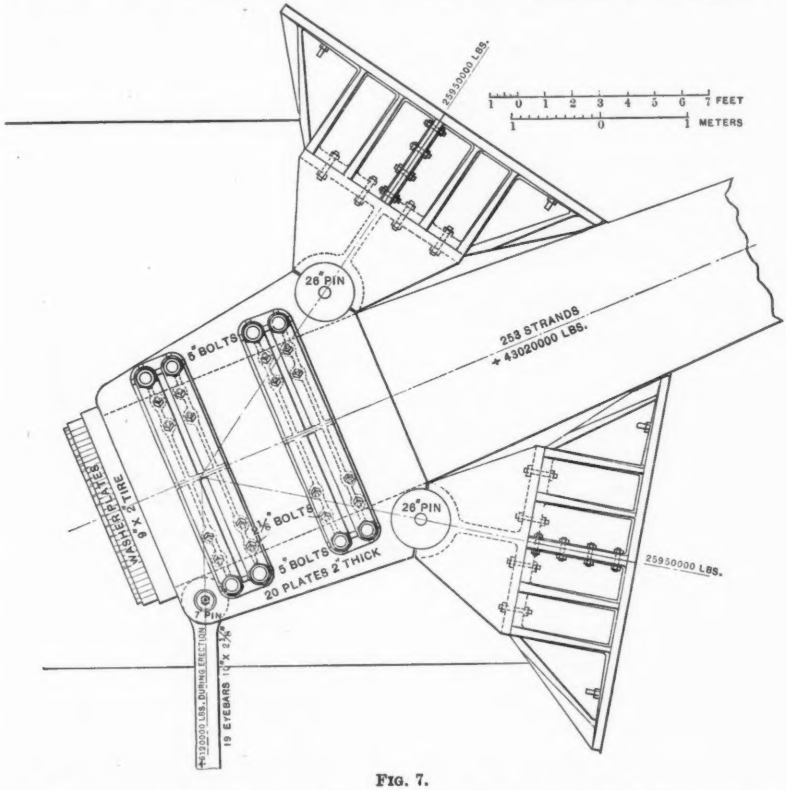


Fig. 7.

the anchorage completed. By this arrangement the cables take hold at once on the anchorage in straight lines without the intervention of eye-bars, and the strains are transmitted in the simplest possible way without the complicated curves commonly used. The cables run through tunnels sufficiently large to walk through conveniently, and the detail at the lower end is in a room about 20 ft. in each direction. The only portions of the work which will not be permanently accessible

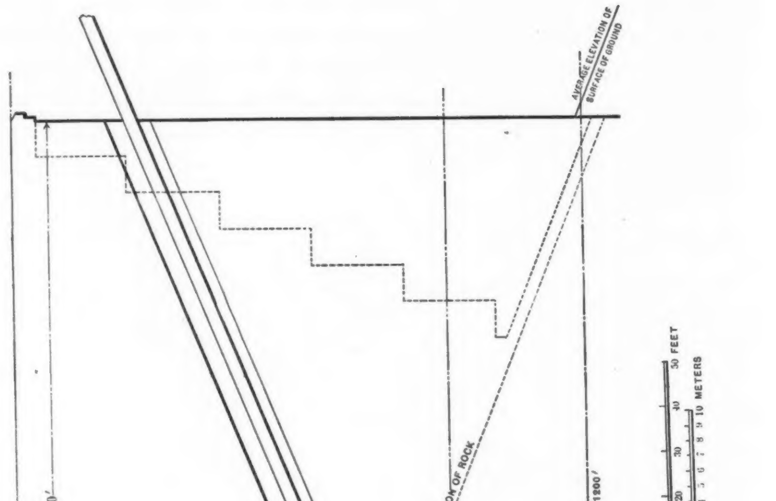

AVERAGE ELEVATION OF SURFACE OF GROUND
180' x 130'
ASSUMED AVERAGE ELEVATION OF ROCK
HORIZONTAL DISTANCE TO INTERSECTION ON TOWER 1200'
−25950000 LBS.
−25950000 LBS.
+612000 LBS., DURING ERECTION
+4327000 LBS.
−4327000 LBS.
10'
50 FEET
10 METERS
AVERAGE ELEVATION OF SURFACE OF GROUND

FIG. 8.

are the eye-bars which form the lower anchorage, and these are only depended on for temporary use.

The calculations referred to above are based on the assumption that the inclination of the cables at the top of the towers is everywhere one vertical to two horizontal; in point of fact, it would be slightly flatter than this, so that the strains in the cables and the reactions on the towers are a little less than has been estimated. The actual inclinations at the top of the towers are according to the following table:

Main cable	1 in 2.196
Backstays	1 in 2.030

The actual length of the cables measured from out to out of the sockets, with an allowance for elongation under strain, is as follows:

Main cable	3 342 feet.
2 backstays, 1 178 ft. each	2 356 "
	5 698 feet.

As there are 253 ropes in each cable and four cables, the total length of rope will be 5 766 376 feet, which, at 10 lbs. per lineal foot, makes a total weight of 57 663 760 lbs. To this must be added the sockets, of which there will be 6 072; each socket will weigh 36 lbs., making the total weight of the sockets 218 592 lbs. The weight, therefore, of the ropes all socketed and ready for erection may be estimated at 57 882 352 lbs.

When the cables are completed the clamps which carry the suspenders will be put on. The form of clamp proposed is shown in Fig. 9, and is quite unlike that commonly used in suspension bridges. The clamp is formed of two steel plates pressed into shape and bound together by eight steel bolts; the lower half is a perfectly plain steel plate, but the upper half has two auxiliary plates riveted on, to hold the saddles which carry the suspenders. By means of cast-iron fillers the irregularities in the cables are filled out, and the whole is then surrounded by a sheet of thin metal about 6 ins. longer than the clamp plates, this thin metal being simply for protection against weather. The clamp-plates are then put on and screwed up tight so that the full friction which can be produced by the bolts is obtained. Two

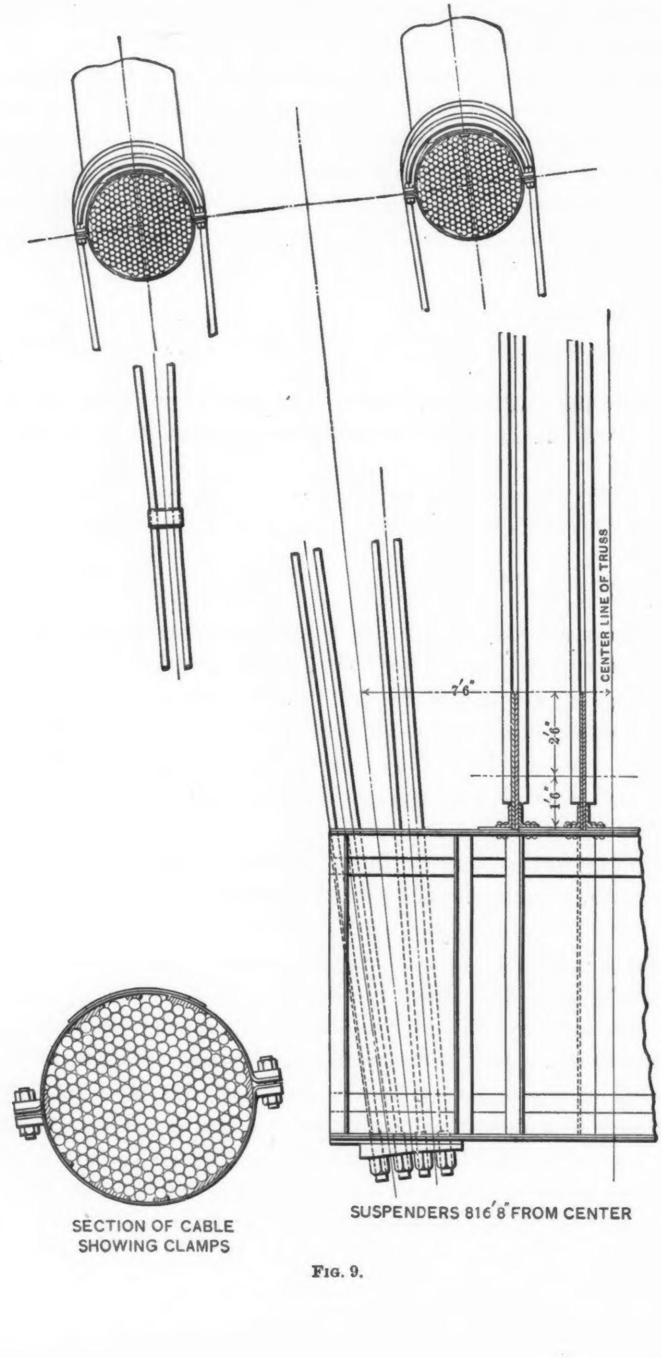

CENTER LINE OF TRUSS
7′6″
2′6″
1′6″
SECTION OF CABLE
SHOWING CLAMPS
SUSPENDERS 816′8″ FROM CENTER

FIG. 9.

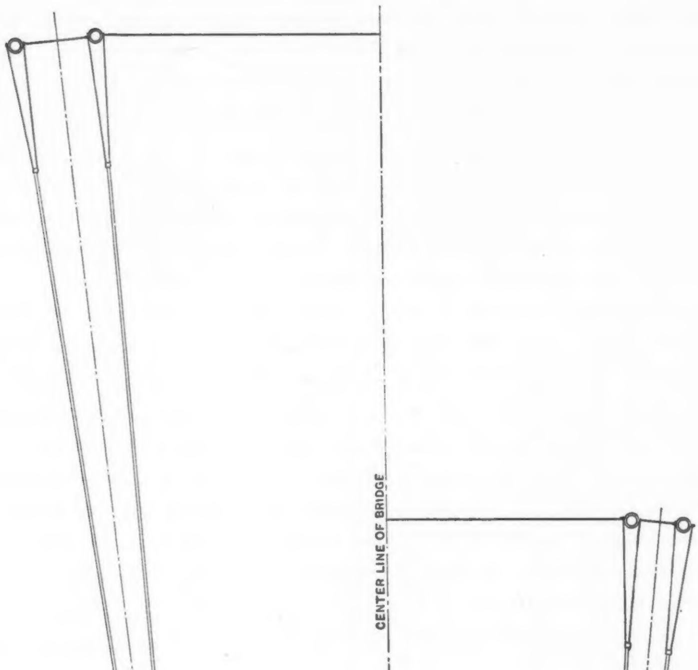
bent saddles of soft metal are then placed on top of the clamp and everything is in readiness to attach the suspenders. Each clamp complete weighs 1 800 lbs., and there are 84 clamps on each cable, making 336 in all. There will also be clamps of different form, but about the same weight at the points where the separation of the ropes begins, 50 ft. from the end of each cable, 24 clamps being required for this purpose. The total number of clamps will, therefore, be 360, the estimated weight of which is 648 000 lbs. The weight of cables and clamps complete will, therefore, be 58 530 352 lbs.

It is thought best not to wrap cables of this size, made of independent ropes, with soft wire as is usually done, but to cover them with a thin layer of some non-conducting substance, which will allow the heat from the sun's rays to reach the metal of the cables no faster than it will be dissipated through the whole volume of the cable. It is premature to say just what the constitution of this non-conducting covering should be; it would probably be finished with a painted canvas surface, and it is not likely to weigh more than 50 lbs. per lineal foot of cable. It would extend from clamp to clamp, covering the projecting ends of the thin metal under the clamps. It must be remembered that it can be easily removed and repaired at any time.

As the cables are first made they will hang in parallel curves between the towers, and as the backstays diverge from the towers there will be a slight transverse tension between the tops of the towers; this, however, is not enough to require any special provision.

The next work, which can be done before the covering is put on the cables, is to cradle them. This cradling will be accomplished by tying the cables on each side together by steel tension bars of varying length, and tying the pairs of cables together by cross-ropes at intervals. These cross-ties and ropes would be attached to every fifth clamp, and the stress in them is comparatively low, amounting to only 90 000 lbs. each, so that ropes of $2\frac{1}{8}$ ins. diameter will be sufficiently large. There will be twelve of these ropes in all, and the total estimated weight of these ropes, together with the ties between cables, is 23 000 lbs.

As soon as the cables are cradled and tied up, everything will be in readiness to attach the suspenders.



SECTION 1383′4″ FROM CENTER. SECTION 1050′ FROM CENTER

FIG. 10.

The total weight of each main cable between vertical intersection points may be taken as follows:

3 325 ft. of cable, at 2 530 lbs. per foot....	8 412 250	lbs.
84 clamps, at 1 800 lbs....................	151 200	"
Cradling-ties..............................	5 750	"
	8 569 200	lbs.
3 000 ft. of covering, at 50 lbs............	150 000	"
Total.............................	8 719 200	lbs.

This divided by 3 200 gives 2 725 lbs. as the average weight per foot of bridge for each cable and connections, or 10 900 lbs. for the four cables.

As the total weight for which the bridge is proportioned is 50 000 lbs. per lineal foot, or 12 500 lbs. for each cable, the weight which must be carried by the suspenders will be 39 100 lbs. per lineal foot for the four cables or 9 775 lbs. for each cable. There are three suspenders to each 100 ft., so that the weight to be carried by each separate suspender is 325 833 lbs.

The arrangement of the suspenders is shown in Figs. 9, 10 and 11. They are wire ropes of the same character and dimensions that are used in the main cables. The detail selected provides for four suspending ropes at each clamp. Each rope would therefore have to carry 81 458 lbs., equivalent to 27 153 lbs. per square inch, or less than half the stress allowed in the main cables.

There are really but two ropes used at each point, each rope being twice the length of the suspender and fitted at each end into a long socket on which a screw is cut. Each rope passes over the saddle and so forms two suspending ropes; the long sockets pass through washer plates under the floor-beams and are adjusted by nuts under these washers, a detail which might be modified in construction. The suspenders are clamped together about 36 ft. below the cables so as to prevent unnecessary vibration, and where it can conveniently be done the cables will be connected with the stiffening trusses.

The estimated weight of the suspenders, including the sockets, is 1 699 500 lbs., to which may be added 30 500 lbs. to provide for the small vibration connections and extras, making the total weight of suspenders 1 730 000 lbs.

The wind strains are transferred to the towers where the stiffening truss passes the towers by cables. There will be sixteen of these cables in all, and the estimated weight of these sixteen cables, including sockets, is 36 650 lbs. The details of this arrangement, which is very simple, will be explained hereafter.

The total weight, therefore, of the rope-work in the bridge, including sockets, will be as follows:

Main cables, as above....................	58 553 352 lbs.
Suspenders and connections.............	1 730 000 "
Wind cables...	36 650 "
Total.............................	60 320 002 lbs.

These finished ropes can be furnished at the bridge site at a price from 5½ to 6 cents a pound, and the cost of placing them ought not to exceed one-half cent a pound. In these estimates the cost of these ropes has been figured at 7 cents a pound, erected, this including both main cables and all other rope-work, which makes the total cost of cables, suspenders and other similar matters, $4 222 400.

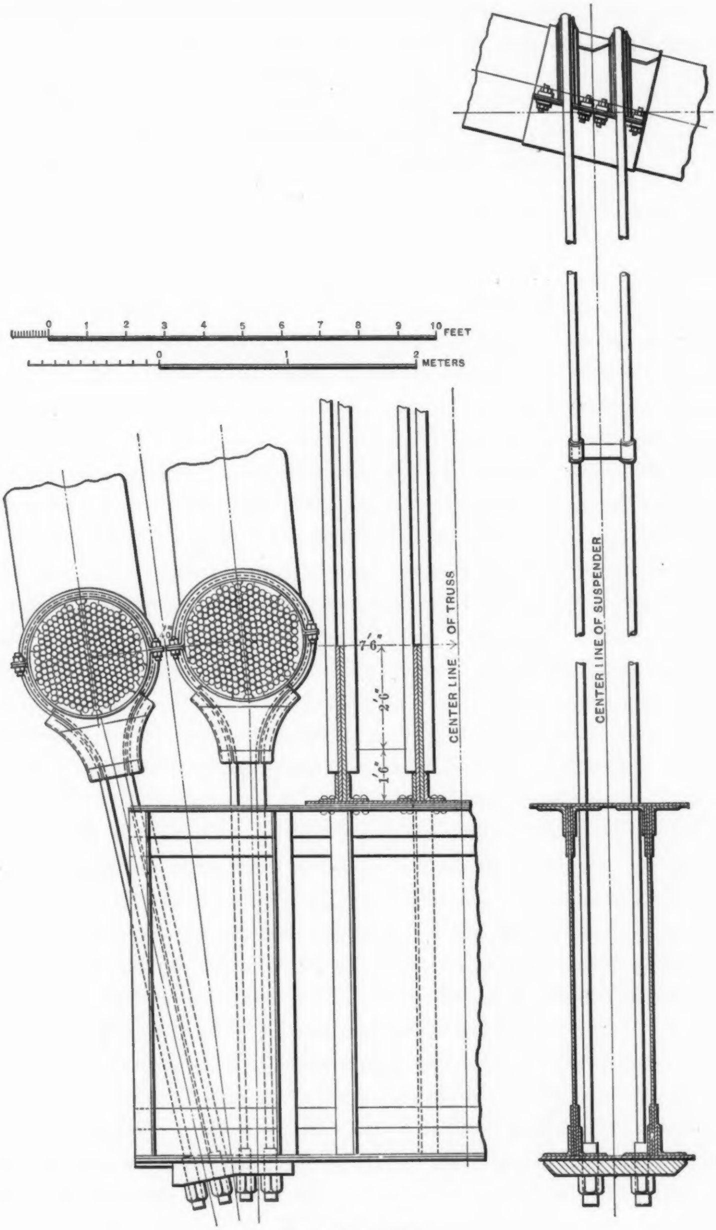
The special details which form the cable connections at the tops of the towers, and in the anchorage, are shown plainly in Figs. 2, 7 and 8. The cable connection on top of each tower-post weighs 454 461 lbs. As there are sixteen posts, the weight of these top connections, including the steel castings, is 7 271 376 lbs.

The connections at the foot of each backstay, including castings and temporary anchorage in the rock, weigh 645 451 lbs., and as there are eight of these, the total weight will be 5 163 608 lbs.

The total weight, therefore, of all material in the special details by which the cables are connected, both at the top of the towers and at the bottom of the anchorage, will be as follows:

Details at top of tower.................	7 271 376 lbs.
" bottom of anchorage...........	5 163 608 "
Total.............................	12 434 984 lbs.

This work is generally heavy and simple, but there is in it some nice machine work, and it will probably be expedient to make all the castings of steel; it is, therefore, estimated at 5 cents per pound in position. This makes the cost of these details $621 749.



SUSPENDERS AT CENTER

FIG. 11.

The cost, therefore, of the cables, including all wire rope and connections, will be as follows:

Rope work, etc.	$4 222 400
Connections at towers and anchorage	621 749
22 000 ft. cable covering, at $1	22 000
Total	$4 866 149

Towers.

The towers naturally follow the cables in studying the design. The support of the cables at each end of the main span consists of two towers, which form a double tower. Each tower is of approximately square section, with four corner posts, each battering one in sixteen in both directions.

In designing these towers the special functions which they have to perform must be considered. The arrangement by which the cables are attached to the top of the towers holds the towers absolutely, there being no movable saddles. Any change of length in the backstays must be taken up by a change in the position of the top of the tower. These movements at the top of the tower, combined with changes in length in the main cables, regulate the position of the suspended superstructure. It is important that the towers should be comparatively slender, so that they can bend without overstraining the metal. As the top of the tower is anchored by the backstays, a broad base is not necessary for stability.

The tower is not exactly square, but on the top the north and south sides are in line with the backstays, and the distance between theoretical intersections is 28 ft. on each side. As, however, the outer cables are lower than the inner cables, the actual distance between centers at the bottom of the castings, or at elevation 559.08, will be 29.18 ft. and 29.55 ft. for the north and south sides and 28.42 ft. and 27.58 ft. for the east and west sides of each tower. At the theoretical intersection point between the bottom strut and the posts at elevation 36, the north and south sides of the tower measure 92.94 and 93.8 ft. and the east and west 93.93 and 94.32 ft. Although the tower is not exactly square, it is so nearly so that the irregularity would seldom be observed. The towers, however, are twisted with reference to each other, and this would be manifest.

Strain sheets have been prepared for these towers, and are given in Figs. 12 and 13, these strain sheets showing the calculated results from the 20 000 000 lbs. imposed on the top of each post, and from the weight of the tower itself, beside the strains due to wind. The towers have been proportioned on the basis of a stress of 20 000 lbs. per square inch from weight alone in the posts, no additional provision being made to resist wind or other extraordinary strains, as they will in no event be more than 25% greater than the strains produced by weight alone. The assumption supposes the cables to have an inclination of two horizontal to one vertical. The real strains in these towers are, therefore, from 1% to 10% less than the calculated strains.

The actual motion in the top of the tower after the completion of work, due to changes in the length of the backstay caused by a maximum moving load, on the basis of a modulus of elasticity of 26 000 000, will be $6\frac{7}{8}$ ins., which corresponds to a stress of 2 176 lbs. per square inch in the posts of the tower. This is less than 11% of the 20 000-lb. stress for which the posts of these towers are proportioned, and the towers have been proportioned on the supposition that the angle of the main cable is two horizontal to one vertical, whereas it is 10% greater, and the reaction on the posts 10% less. The stresses in the posts, after allowing for bending, are only 1% more than the calculated strain. The motion at the top of the posts, caused by a change of temperature of 60°, will be less that $5\frac{1}{4}$ ins., corresponding to a stress of 1 450 lbs. per square inch in the posts, which may exist in either direction from a mean.

During erection a much greater motion may be required, especially if no temporary supports are put in for the backstays. A greater motion can be obtained without overstraining the metal, in two ways: By omitting the permanent diagonal bracing and putting in timber bracing, which can be so wedged as to bend the tower; by inserting hydraulic presses in the castings under the posts next to the river, so that the whole tower can be thrown out of plumb.

The section of each post varies from 1 051 sq. ins. at the top to 1 145 sq. ins. at the bottom. Each post is 8 ft. square, and the details of construction are shown in Fig. 14. This post is divided into quarters and made in sections, each 24 ft. long, breaking joints with these sections, so that there would be one horizontal quarter joint every 6 ft. Each quarter section 24 ft. long would weigh less than 12 tons, a

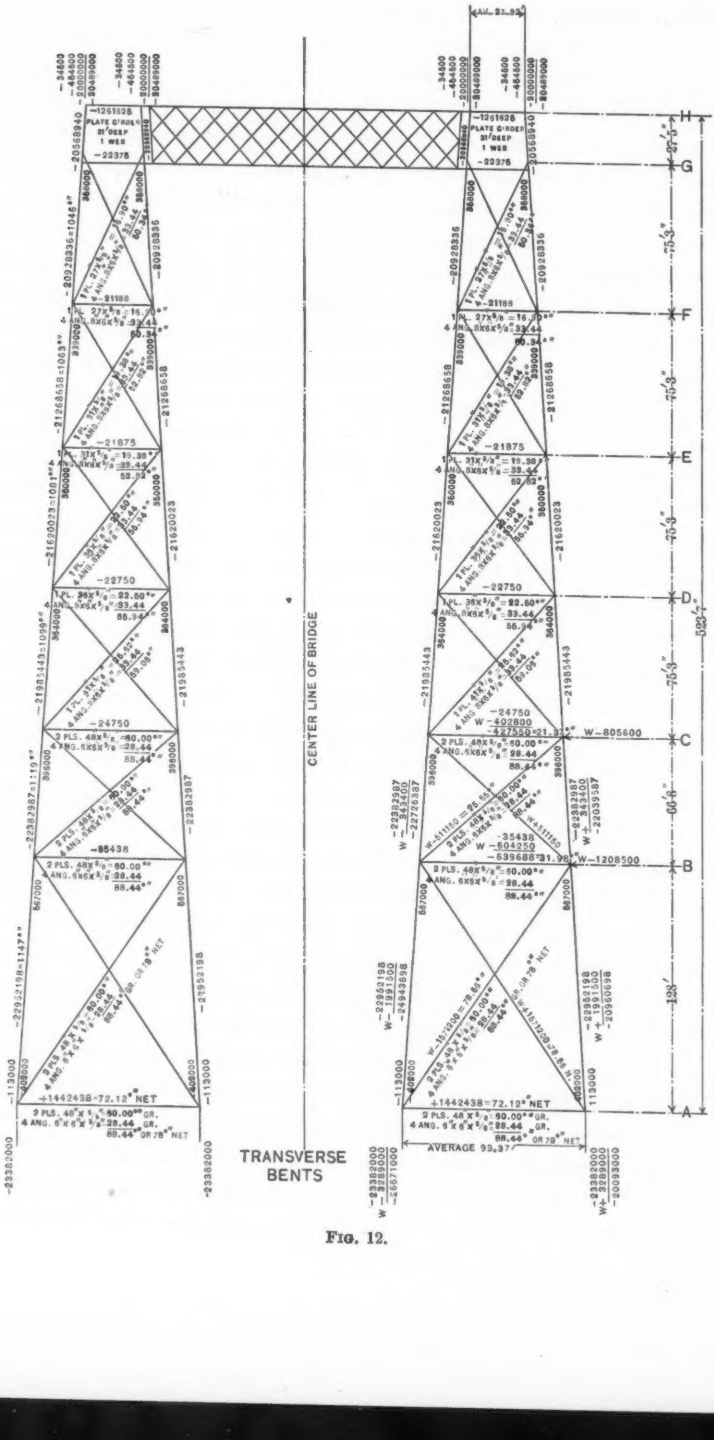

CENTER LINE OF BRIDGE
TRANSVERSE BENTS
PLATE GIRDER 31' DEEP 1 WEB
AVERAGE 93.37'

FIG. 12.

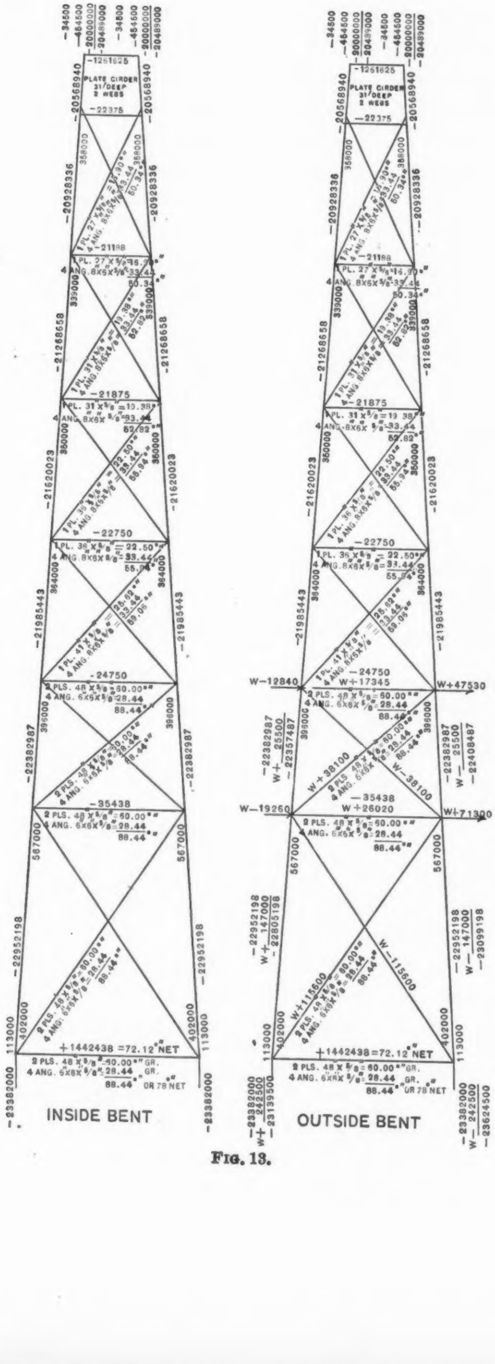


FIG. 13.

weight which can easily be handled. All the heavy riveting around the corners would be shop driven, and it is proposed to use $1\frac{1}{4}$-in. rivets for this portion of the work. The splices at the joints, both vertical and horizontal, would be field driven, $\frac{7}{8}$-in. rivets being used in these places, and could, if necessary, be hand driven. At intervals of 24 ft. diaphragms would be built in each post, these coming opposite one of the joints (as shown in the intermediate section in Fig. 14), the function

Bill for One-Quarter Post Section.

1 Plate, 48" x $1\frac{11}{16}$", 24' long.	1 Plate, 21" x $1\frac{1}{16}$" to $1\frac{5}{8}$", 24' long.
1 " $46\frac{5}{16}$" x $1\frac{11}{16}$", 24' long.	1 Angle, 9" x 9" x 1", 24' long.
1 " 22" x $1\frac{1}{16}$" to $1\frac{5}{8}$", 24' long.	1 Corner Plate, 25" x $\frac{3}{4}$", 24' long.
2 Splice Plates, 15" x $\frac{3}{4}$", 24' long.	

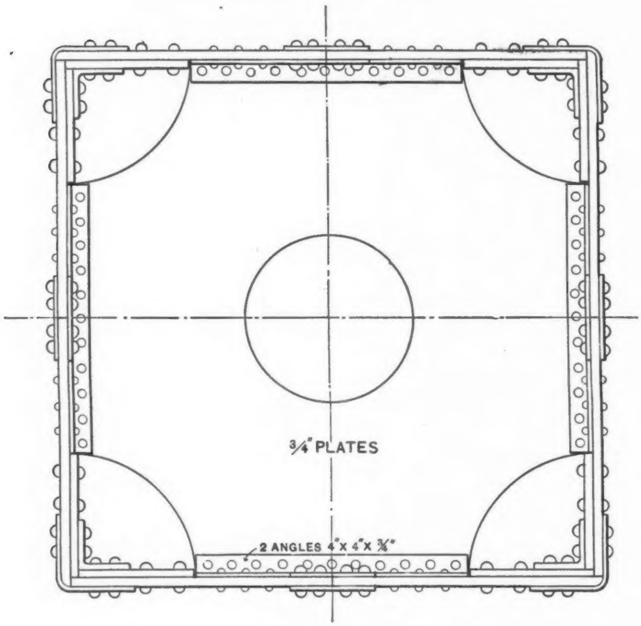


Fig. 14.

of these diaphragms being the same as that of the diaphragms in a bamboo rod. At the top two extra cross webs would be built into the post to support the steel casting.

At the bottom the post would rest on a large casting. For convenience of inspection, a hole is made through the middle of each diaphragm, and a series of ladders would reach from diaphragm to diaphragm, by which inspectors could pass through the whole interior

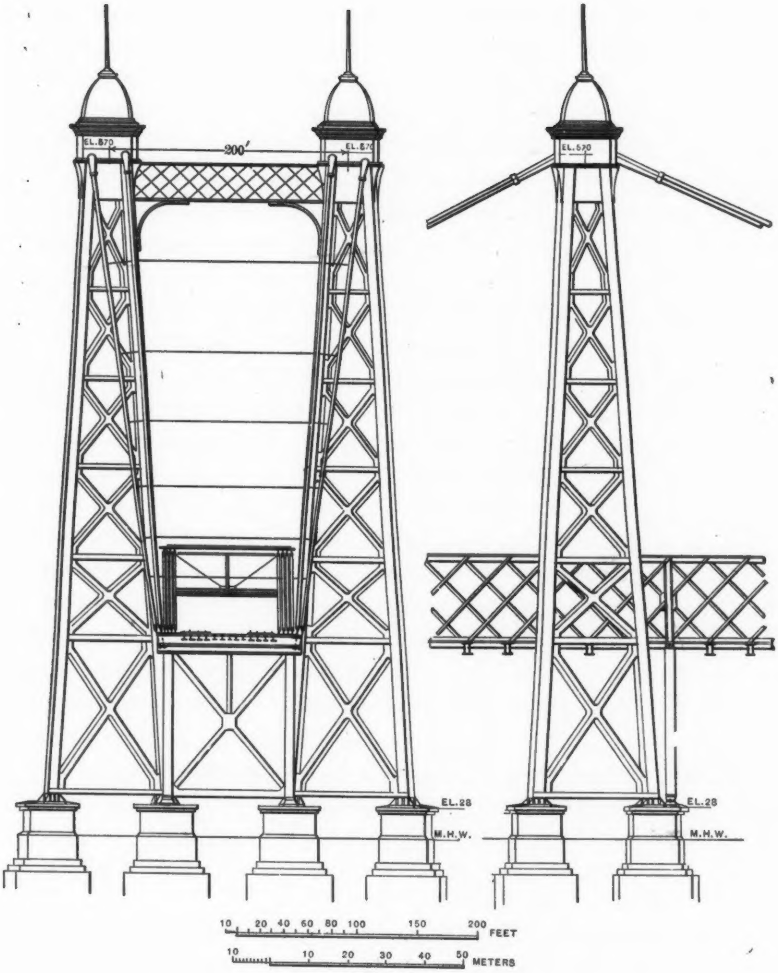

EL. 570
200′
EL. 570
EL. 570
EL. 28
M.H.W.
EL. 28
M.H.W.
10 20 40 60 80 100 150 200 FEET
10 10 20 30 40 50 METERS

FIG. 15.

of the post, a manhole being placed near the base, through which they could enter. At the bottom each post would be held down by an anchor bolt at each corner, though this is hardly a necessary provision.

These posts have been carefully estimated in detail, the weight of one post being 2 182 000 lbs., or 8 728 000 lbs. for the four, including diaphragms, ladders and everything else.

At the top the four posts are connected by girders 31 ft. deep, there being two girders on each longitudinal side and one on each transverse side. The depth of these girders is fixed by the riveted connection between the double girders and the posts, this connection being necessarily long enough to transfer the whole strain from the vertical bars to the post. These six girders are estimated to weigh 264 000 lbs.

The tower is braced on each side between the four posts, this bracing being divided into six panels, the second panel from the bottom corresponding in height to the depth of the stiffening truss, this arrangement being adopted so that the wind strains can be thrown from the stiffening truss into the tower at the panel points of the bracing. The arrangement of this bracing is given in Fig. 15. Above the stiffening truss the bracing has comparatively little to do, and is made in the form of a single web with broad angles on the edges. From the top of the stiffening truss downward, where the wind strain is to be resisted, the bracing is double webbed and materially heavier. At the bottom the floor posts are tied together by heavy riveted ties, which pass outside the posts, but form the bottom member of the bracing. The weight of the bracing for one tower complete has been estimated at 2 389 000 lbs.

The towers are connected at the top by a light lattice truss bridge, which has comparatively little work to do, but which will add to the lateral stability, and be a convenience, both during erection and afterward. This truss bridge complete is estimated to weigh 98 000 lbs., or 49 000 for each single tower.

Each post rests on a large bottom casting, which should be made of steel. This casting would be made in four principal parts bolted together, and should be machined to a true plane on the bottom, as the pressure on the bottom will be 1 000 lbs. per square inch. This casting, together with the anchor bolts, is estimated to weigh 130 000 lbs., or 520 000 lbs. for each tower.

The total weight of the structural portions of the tower will then be as follows:

Posts	8 728 000 lbs.
Girders	264 000 "
Bracing	2 389 000 "
Truss	49 000 "
Castings and anchor bolts	520 000 "
Total	11 950 000 lbs.

As there will be four of these towers, two at each end, the total weight of metal in the towers will be 47 800 000 lbs. This entire work should be open-hearth steel of the quality ordinarily used for structural purposes. The sections are so heavy that the edges would all have to be planed, and it would all be solid drilled work; special machinery would be required for its manufacture, but the order is so large that the cost of this special machinery when averaged over the whole work would be no greater than the wear of ordinary tools. In open competition this work ought to be let for a very low price per pound; if estimated at 4 cents per pound, there results for the cost of the towers $1 912 000.

Fig. 15, showing the general elevation and tower, shows the tower as finished with a room about 50 ft. square on top, surmounted by ornamental work terminating in a flagstaff. This covered room is necessary to house the cable connections, but as the floor of this room will be 560 ft. above the water, or nearly twice as high as any structure now existing in New York City, and higher than any structure in the world except the Eiffel Tower, a considerable revenue could probably be derived by providing elevators and taking visitors to the top of the towers. As the elevators and housings on top of the towers do not form a portion of the structural work, they are not included in the estimate.

Foundations.

The average depth from mean high water to rock at the site of each tower is assumed to be 140 ft. In order to prevent any possible disturbance from expansion and contraction of transverse members at the feet of the metallic towers, it is thought best to rest each post on an entirely independent foundation. There would, therefore, be four independent foundations under each tower, or eight on each side of the

river, making sixteen in all. Of these the two center ones next to the river, on each side, would have to support the reaction of the stiffening truss as well as the weight of the tower post, and they are therefore made larger than the others. The plan of half of the tower foundations is shown in Fig. 16.

Each separate foundation consists of a masonry pier of granite 58 ft. high, finishing 28 ft. above mean high water, and terminating at the base at an elevation 30 ft. below mean high water. It is proposed to make these piers of an exceptionally good class of masonry and to allow a maximum pressure of 20 tons per square foot on the granite, and of 1 000 lbs. per square inch on the under side of the casting which

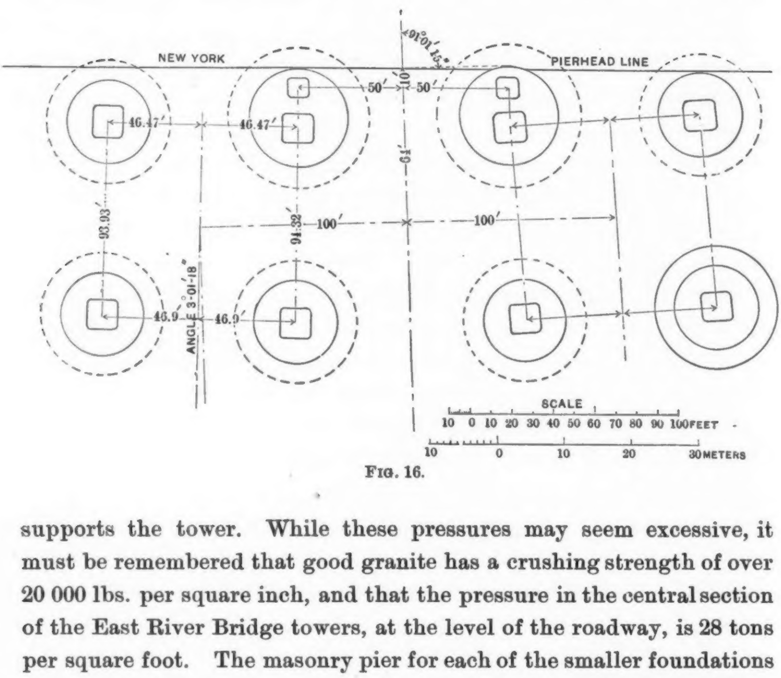


Fig. 16.

supports the tower. While these pressures may seem excessive, it must be remembered that good granite has a crushing strength of over 20 000 lbs. per square inch, and that the pressure in the central section of the East River Bridge towers, at the level of the roadway, is 28 tons per square foot. The masonry pier for each of the smaller foundations contains 2 700 cu. yds., and that for the larger foundations 3 900 cu. yds. Estimating this work at $30 per cubic yard, the masonry for the smaller foundations becomes worth $81 000, and for the larger foundation, $117 000.

Each of the smaller foundations would rest on a cylinder 60 ft. in diameter and 110 ft. high, thus containing 311 000 cu. ft., or, say,

11 500 cu. yds. Each of the larger foundations would rest on a cylinder 70 ft. in diameter, thus containing 423 330 cu. ft., or, say, 15 700 cu. yds. If the cost of this portion of the work is estimated at $20 per cubic yard, the cost of each of the smaller foundations becomes $230 000, and that of each larger foundation $314 000.

The cost of each of the smaller piers complete, including both masonry and foundation, becomes $311 000, and of each of the larger piers, including both masonry and foundations, $431 000. As there are at each end of the bridge six of the smaller piers and two of the larger, the cost of the substructures of each of the double towers will be $2 728 000. The total cost of the foundations for the towers on both sides of the river will then be $5 456 000.

This estimate is believed to be at least $1 000 000 more than the actual probable cost of such work, but this paper is dealing with the general subject of a suspension bridge, and precise estimates of the subaqueous portion really pertain to more specific subjects.

The pressure on the bottom of the foundations after deducting the weight of the material displaced, and estimating the weight of a cubic foot of masonry or foundation at 150 lbs. in air, 87 lbs. in water, or 50 lbs. in mud, is 9 304 tons per square foot for the smaller, and 9 306 tons for the larger.

Anchorages.

The anchorages at each end of the bridge would be divided into two parts, each of which anchors two cables, the position of these anchorages being shown in Fig. 1.

The anchorage has no duty to perform except to provide weight, and may be built of a very cheap class of masonry or of concrete. Any class of work which is entirely free from voids and weighs at least 140 lbs. per cubic foot, or 3 780 lbs. per cubic yard, will answer this purpose. The exposed sides of the anchorages should be faced with a good class of masonry; brick would answer, but granite would be more in keeping with the massiveness of the work. The top will not require a coping, but should be covered with Portland cement concrete or some form of pavement which will keep out water; there is no reason why buildings should not be erected on top of the anchorages.

There will be two tunnels running through each anchorage, each of which should be lined with brick, and be large enough for con-

venient inspection of cables, and perhaps, also, for running a carrier during erection. At the lower end of each cable there will be a room in which the detail connection is placed, and it will probably be expedient to have some kind of a staircase placed in a small shaft by which these two rooms can be reached. The bearing of the castings must be taken on granite masonry of very high quality, the pressure on the bottom of the castings being 1 000 lbs. per square inch, and enough of this masonry has been provided to reduce the pressure on the cheap masonry to 250 lbs. per square inch.

Each anchorage would consist of a single block of masonry, a longitudinal section of which is given in Fig. 8. It is 180 ft. long, 130 ft. wide, and the top finishes at elevation 155, this being the elevation of the rails. The horizontal distance from the theoretical intersection on the top of the tower to the theoretical intersection at the bottom of the anchorage is taken as 1 200 ft. The lower intersection is assumed to be at elevation 60, so that the vertical difference in height between the two intersections is 510 ft.

The volume of material above the theoretical intersection point is 2 223 000 cu. ft., which at 140 lbs. per cubic foot, weighs 311 220 000 lbs. The angle at which the cables take hold of the anchorage is one vertical to 2.524 horizontal. The vertical lift will, therefore, be 31 695 721 lbs. Taking this from the weight of the anchorage, the weight left to resist the horizontal pull is 279 524 279 lbs. Assuming a coefficient of friction of 60 per cent., the frictional resistance of this weight is 167 714 567 lbs. Dividing this last quantity by 80 000 000 lbs., the assumed horizontal strain in cables, gives a factor of stability of 2.09. This is without taking into consideration the strength of the additional anchorage in the rock below, nor including the weight of any buildings or other structures which may be erected on top of the anchorages.

The quantity of masonry in each anchorage above the points of intersection is 2 223 000 cu. ft., or 82 333 cu. yds. As, however, the foundation may be below the assumed level of the intersection, this masonry is estimated as 100 000 cu. yds. The greater part of this would be concrete or a cheap class of masonry, but 1 375 cu. yds. will be high-class granite work. Estimating the whole mass of masonry at $6 per cubic yard, and adding $44 per cubic yard (making a total cost of $50) for the high-class granite work, there results as the cost

of one anchorage \$660 500. There will be two anchorages at each end of the bridge costing \$1 321 000; the total cost of the anchorages at both ends of the bridge will, therefore, be \$2 642 000.

Suspended Superstructure.

The suspended superstructure embraces the floor beams and the stiffening truss, with all the necessary cross-bracing, laterals, etc. The stiffening truss is the principal feature of the whole, and its peculiar function is such that the calculation of the exact strains is a work of extreme difficulty. It is possible, however, in an investigation of strains to bring them without extreme difficulty within limits which they surely will not pass in either direction, and as everything is based on elastic changes in which there must always be a small percentage of irregularity, these results are at least as accurate as the material is uniform, and the error will always be on the safe side.

A stiffening truss with a hinge at the center has the advantage of greater simplicity in the calculations, but the details of the hinge are much more objectionable than any irregularities of strain which might occur, and a continuous stiffening truss without a hinge has been used in this design.

The functions of a stiffening truss may be considered in two ways. It may be regarded simply as a floor stiffener, preventing short local changes; or it may be considered as a complete stiffening truss which distributes the entire moving load with practical uniformity over the whole length of the structure. The former is the usual function performed by the stiffening truss of a long-span highway bridge; the latter is the function which a stiffening truss must perform in a short-span bridge or in a railroad bridge of moderate length.

In the former case the proportioning of the stiffening truss is comparatively simple. The greatest possible distortion of the cables under a moving load must be calculated, the moving load being considered uniform for such distance as will produce the greatest distortion; the amount of deflection which will occur within the limits of this load must then be determined, and the stiffening truss made of such depth that it can deflect this amount without overstraining the metal in the chords; as the deeper the truss, the greater the unit stress in the chords for the same deflection, it follows that the stresses must in this instance be kept down by using a shallow truss. This works

well in highway bridges; it would work equally well in a railroad bridge of such dimensions that the dead load would be so great in proportion to live load that the deflection would not exceed the limit over which trains could conveniently be run at high speeds.

In the case of a railroad bridge in which the dead load is light in proportion to the moving load the stiffening truss must be proportioned on such a basis that it will virtually distribute the whole moving load uniformly over the entire length of span. As the deflection of the stiffening truss has little influence in such calculations, the deeper the stiffening truss, the less will be the stresses in the chords.

In the present case the dead load is so great in proportion to the moving load that the distortion of the cables will be comparatively small, even under the passage of trains; it will, however, be so great that if the stiffening truss performed no other functions than that of a floor stiffener, the deflection might disturb the rapid passage of trains. In this case, the proper method of proportioning a stiffening truss is, to decide first what deflection will be allowable under maximum conditions; then to determine what depth of stiffening truss will correspond to the maximum unit stresses which it is considered wise to adopt; then to determine the amount of difference in load which will be required to create a corresponding distortion in the cables; by deducting this difference from the total moving load, the amount of moving load is determined which the stiffening truss must distribute. On this basis a stiffening truss may be proportioned, though the exact strains must be a matter of subsequent computation.

The condition of loading which will cause the greatest deflection in the loaded portion of the stiffening truss will occur when the maximum moving load covers one-half of the 2 800 suspended feet of stiffening truss, occupying 1 400 ft. on either side of the center; this is also the case in which all calculations are most simple. A limit of deflection of one four-hundredths of the half span, or 3½ ft. in 1 400 ft., corresponds to a 1% grade at each extreme end of the deflection, and has been selected as the limit in this case.

The moving load which the cables are capable of carrying is equivalent to 11 000 lbs. per lineal foot over the entire structure, and it is assumed that this load is distributed over the equivalent of six railroad tracks, corresponding to 1 833 lbs. per foot

of track. In estimating the effects of an unequal load a weight of 12 000 lbs. per lineal foot is taken in accordance with the provisions stated at the beginning of this paper. While it may be considered that the load per foot on one-half or one-third of a span ought to be more than 10% greater than the load per foot on the whole span, it must be remembered that the peculiar conditions of this bridge are such that it is only under very rare conditions that any considerable portion of the moving load must be distributed by the stiffening truss. In fact two passenger trains could cross this bridge side by side without disturbing the position of the cables beyond the limits of deflection which are permissible; it is only when the load exceeds that of two maximum passenger trains that the stiffening truss has any duties to perform beyond that of a floor stiffener.

The excess load required to produce a distortion of 3.5 ft. at the quarter on a 2 800-ft. span with a versed sine of 310 ft. (which corresponds to the design), will be 9.424% of the load on the unloaded portion. Taking the dead load at 39 000 lbs. per lineal foot, 9.424% of this is 3 675 lbs.; deducting this from 12 000 lbs., there remains 8 325 lbs. as the weight per foot to be distributed by the stiffening trusses, or 4 162 lbs. for each truss.

By the use of nickel steel, as hereafter explained, considerably greater strains may be used in the stiffening truss than would be considered good practice with ordinary structural steel; a stress of 17 000 lbs. per square inch has therefore been selected as the limit. This having been assumed, the depth of the stiffening truss may be calculated by the following formula:

$$d = \frac{5\ S\ l^2}{24\ E\ v_o}$$

in which

S = stress per square inch = 17 000

E = modulus of elasticity = 30 000 000

v_o = deflection = 3.5

l = span = 1 400

Solving this quotation, $d = 66.11$.

For convenience the depth has been made 66 ft. 8 ins., equal to $200 \div 3$.

The required section of the chords of the stiffening truss will then be determined by the following formula:

$$a = \frac{\frac{w}{2} l^2}{8\, a\, s}$$

in which

$$\begin{aligned} d &= 200 \div 3 \\ l &= 1\,400 \\ s &= 17\,000 \\ w &= 4\,162 \end{aligned}$$

Solving this equation, $a = 450$.

In the design the chords of the stiffening truss have a gross section of 600 sq. ins. and a net section of 560 sq. ins.; the net section is 24% greater and the gross section 33% greater than the approximate calculation requires; it is expedient, however, to provide an excess of metal above that required by these advance calculations. The gross section is the one to be used in calculating deflections. Should the modulus of elasticity assumed (30 000 000) be criticised as being too high, it must be noted that this modulus is applied to the calculated section of the chord, whereas the actual section would be materially increased by splices and connection plates, so that a modulus of 27 500 000 in the metal would correspond to at least 30 000 000 in the calculated section.

This is a simple solution and gives data to start from, but while considering the effect of the distorted cables in carrying unequal loading, it does not consider the bending effects on the stiffening truss due to the deflection of the cables as a whole, all of which must be taken into consideration in the final calculations. In these final calculations it is necessary to assume certain sections of cables and stiffening truss chords as well as loads. It is not possible to make a strain sheet in advance and then proportion the sections in accordance with the strains. Everything is determined by deflections, and deflections are themselves determined by sections.

A careful investigation of the theory of the stiffening truss has been made on entirely independent lines by Mr. Charles S. Peirce. By the use of the formulas which this investigation has developed, the strains in the stiffening truss have been calculated for three different conditions. In the first of these a moving load of one-third the length

of the span, 3 100 ft., is assumed to occupy the first third of the 3 100 ft. In the second supposition it is assumed to occupy the second and third sixths of the 3 100 ft., the end of the load being at the center. In the third supposition it is supposed to occupy the central third of the 3 100 ft. The moments developed by these calculations are a satisfactory confirmation of the capacity of the stiffening truss.

In this connection it is interesting to compare the duty which is to be performed with that on the East River Bridge. The stiffening

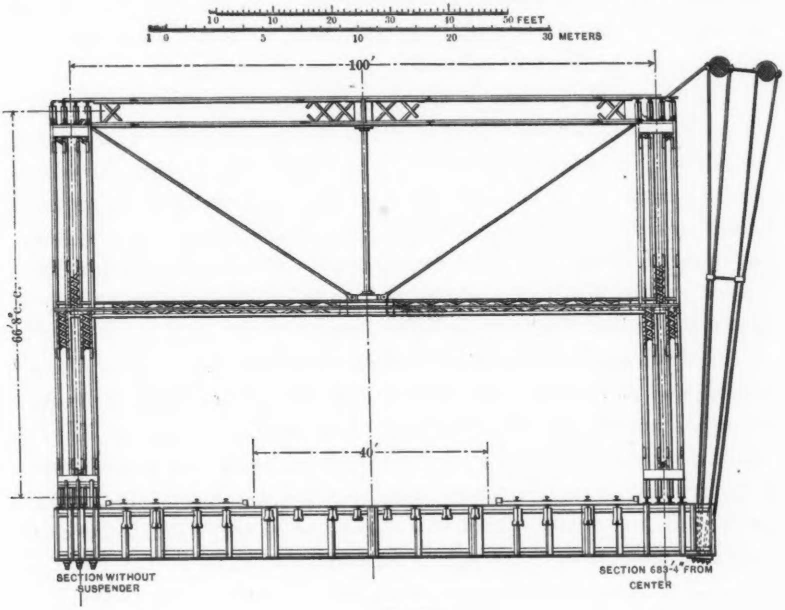


Fig. 17.

truss of the East River Bridge is simply a floor stiffener; both chords are cut at the centers of both the main and the side spans, having sliding joints which can transfer no bending strains whatever and a comparatively small amount of shear. The trains which run over this bridge weigh about 100 tons each, or half a ton per lineal foot, about two-thirds the weight of a first-class passenger train, and they are about half as long as an ordinary passenger train; and yet, in spite of the lightness and theoretical inadequacy of the stiffening truss, the action of the bridge under these trains is entirely satisfactory.

In all these calculations no account has been taken of the stiffness of the cables themselves, which are more than 3 ft. in diameter, of the chords of the stiffening truss, which are 4 ft. deep, nor of the stringers of the floor system, all of which would have decided influences of their own.

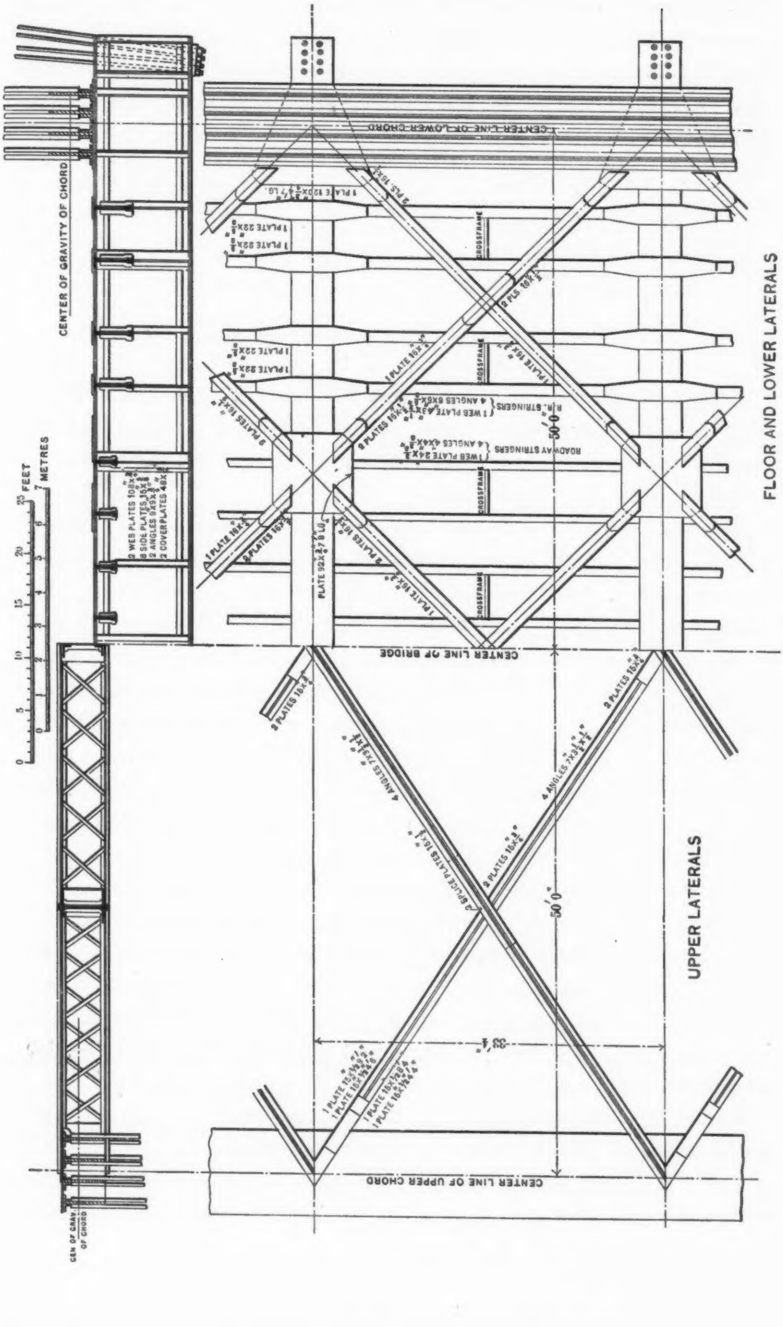
The two stiffening trusses designed are each 66.67 ft. deep between centers of gravity, or 70 ft. over all. They are placed 100 ft. between centers. There is a stiff riveted lateral bracing between the top chords and a transverse bracing, as shown in Fig. 17, at every panel point. The floor system is entirely below the bottom chord and the bottom laterals are built in as a portion of this floor system. The webs are riveted lattices with four independent lines of bracing.

The suspended portion of the truss is carried by the floor beams, and as its weight exceeds the amount of moving load which has to be distributed, its action really amounts to varying the portion of its own weight which is transferred to the floor beams, there never being any conditions under which any portion of the weight of the floor system has to be transferred to the stiffening truss. Beyond the limits of the suspenders the floor beams are hung from the stiffening truss to which they transfer the weight of the floor system.

The arrangement of the floor system as worked up is shown in a general way in Fig. 18. The floor beams are strong enough to carry the whole weight from truss to truss, thus leaving a clear space for the whole distance. The two double-track railroads are placed next to the trusses, thus reducing the weight of the floor beams to a minimum, while the possible deflection of one end of the beam below the other is found not to be enough to produce trouble.

There will be eight railroad stringers in each panel and eight lighter stringers which carry the roadway or the rapid transit tracks. Each railroad stringer is proportioned for a total load of 4 230 lbs. per foot of stringer, the strains in the extreme fiber being 9 025 lbs. per square inch of gross section, and weighs 6 300 lbs. Each light stringer is proportioned for a total load of 1 000 lbs. per foot of stringer, the strain in the extreme fiber being 9 620 lbs. per square inch of gross section, and weighs 2 540 lbs.

The floor beams are proportioned to carry a weight of 45 667 lbs. at each single railroad stringer connection, and for a load of 100 lbs. per square foot on the 40 ft. between railroad tracks, besides a weight of



FLOOR AND LOWER LATERALS
UPPER LATERALS
CENTER OF GRAVITY OF CHORD
CENTER LINE OF LOWER CHORD
CENTER LINE OF BRIDGE
CENTER LINE OF UPPER CHORD
50' 0"
FEET
METRES

FIG. 18.

280 000 lbs. at each end from the stiffening truss. Under these conditions the strain in extreme fibers of gross section is 12 938 lbs. Each floor beam is really a box girder with two webs, and weighs 179 000 lbs. The total weight of the metallic floor system is therefore as follows:

	Per panel.	Per foot
Floor beams	179 000 lbs.	5 370 lbs.
Railroad stringers	50 400 "	1 512 "
Rapid transit stringers	20 320 "	610 "
Lower laterals and connections	24 880 "	746 "
Total	274 600 "	8 238 "

The upper laterals and transverse bracing together weigh 48 000 lbs. per panel, making the total weight suspended, exclusive of the weight of the stiffening trusses themselves, 322 600 lbs. per panel, or 9 678 lbs. per lineal foot of bridge.

Each chord of the stiffening truss has, as has been already stated, a gross section of 600 sq. ins., and the weight of each chord per lineal foot, including splices and connections, is estimated at 11 100 lbs. Each of these chords is made with four webs, the details being as shown in Fig. 17. The arrangement of the webs of the stiffening truss is also shown in Fig. 17. The webs are made uniform for the entire suspended portion of the stiffening truss. Each web member has a total gross section of 53 sq. ins. and a net section of 41 sq. ins., and under the extreme conditions which have been specified above, namely, a moving load of 8 325 lbs. per foot of bridge, exclusive of that which is distributed by the distortion of the cable, these members are subjected to a strain of 7 855 lbs. per square inch of net section, and 6 373 lbs. per square inch of gross section, these strains occurring in the same member in both directions. The web as so designed weighs 3 240 lbs. per lineal foot.

The dead weight of floor, including ties, rails and other work, has been assumed at 3 000 lbs. per lineal foot of bridge, being 500 lbs. for each railroad track and 1 000 lbs. for the intermediate 40 ft.

The lower laterals act only in tension, and their weight, as estimated, includes a large amount of detail connections.

The top laterals and transverse bracing are determined by minimum sections for the most part instead of by strains. The upper laterals

weigh 750 lbs. per lineal foot, and the transverse bracing 690 lbs. The total weight, therefore, of the suspended superstructure per lineal foot may be taken as follows:

Metallic floor as above	8 238	lbs.
Stiffening truss chords	11 100	"
Stiffening truss webs	3 240	"
Upper laterals and cross-bracing	1 440	"
Total metal work	24 018	"
Tracks and flooring	3 000	"
Total	27 018	"

The total dead load is therefore as follows:

Cables and connections (page 493)	10 900	lbs.
Suspenders and connections (page 493)	618	"
Suspended superstructure	27 018	"
	38 536	"
Add for telegraph line and sundries	464	"
Total	39 000	"

This leaves 11 000 lbs. of the total 50 000 lbs. available for moving load, as already stated, which may fairly be considered a margin of 2 000 lbs. over anything that is likely ever to occur.

The total length of the stiffening truss from out to out, including the 500-ft. spans at each end, is 4 100 ft. Assuming chords and floor system to be uniform throughout, the weight of this 4 100 ft., taken at 24 000 lbs. per lineal foot, will be 98 400 000 lbs.

This, however, includes the weight of the heavy floor beams within the suspended length, while there are four floor beams entirely omitted at the supporting points and thirty-six floor beams which are themselves suspended from the chords. Neglecting one end floor beam, as the estimate has been made on a basis per lineal foot, and assuming that the floor beams hung from the chords are 30 000 lbs. lighter than the others, there is a deduction on this account as follows:

3 floor beams at 179 000 lbs	537 000	lbs.
36 floor beams reduced, at 30 000	1 080 000	"
	1 617 000	"

On the other hand, the webs near the supporting bents will have to be reinforced, which can be done by making the members of greater width than elsewhere. As there are no reverse strains here, it is thought right to fix the limit of stress at 20 000 lbs. per square inch of net section. On this basis the additional metal required in the webs is 3 418 000 lbs.

To this must be added the weight of four vertical posts over the rocking bents, and four vertical posts and two portals at the ends of the continuous superstructure.

The weight of the entire suspended superstructure will then be as follows:

4 100 feet (page 515)	98 400 000 lbs.
Additional metal in web	3 418 000 "
Vertical posts over rocking bents	545 000 "
End posts	467 000 "
Portals	140 000 "
Total	102 970 000 "
Deduct for floor beams	1 620 000 "
	101 350 000 "

At the center of the bridge the cables are so little above the floor beams that the stiffening truss must be considered as fastened to the cables longitudinally at this point, a condition which is assumed in the refined calculations of strains; as it is continuous it must be free to move longitudinally at all other points, and especially at the ends. As the continuous truss is 4 100 feet long, a motion due to the effect of temperature on 2 050 ft. must be provided for at each end, this being 0.82 ft. for 60° of temperature; a possible motion of 1.64 ft. must therefore be provided at each end of the stiffening truss, or 0.82 ft. from either side of a mean. This motion is too great to be accommodated by roller bearings of the ordinary kind, and the design places the stiffening truss on rocking bents, which are shown in Figs. 15 and 19. The possible reaction at points 3 100 ft. apart is assumed to be 10 736-000 lbs., and this is taken on vertical posts, the pair of posts under the two trusses being braced together, thus forming a rocking bent, which is supported on two of the cylinders which form the tower foundations. These special cylinders have therefore to sustain this

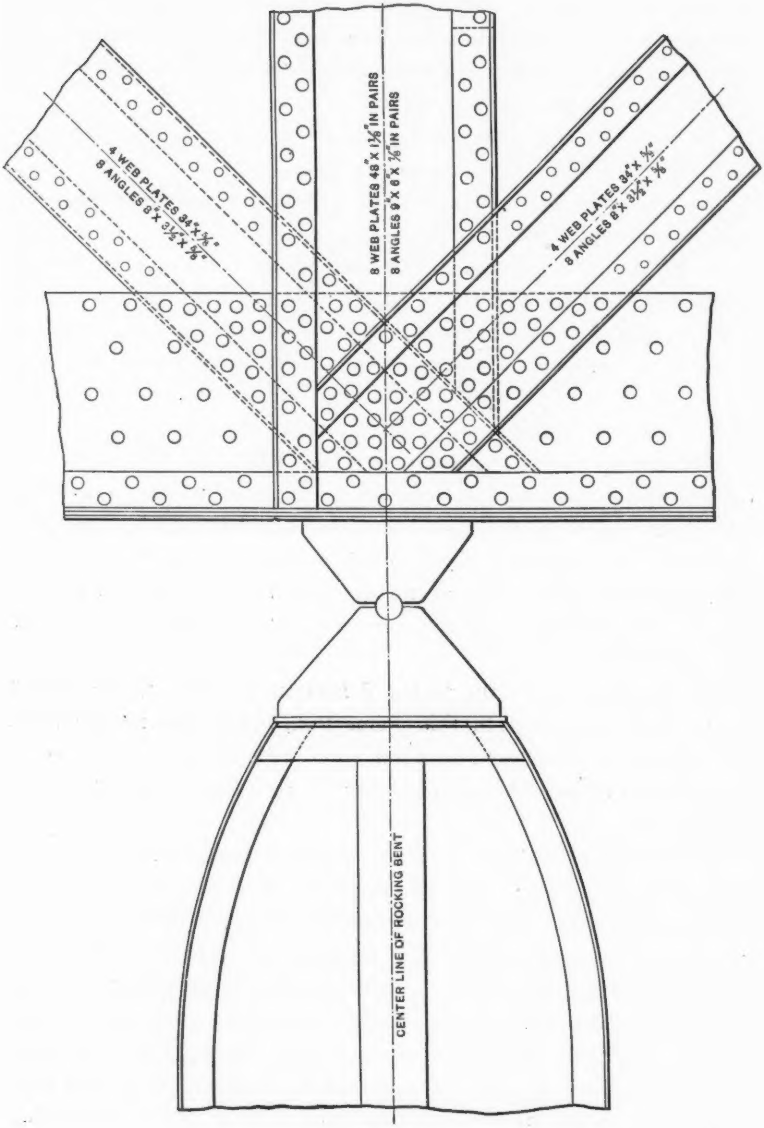

4 WEB PLATES 34" X 5/8"
8 ANGLES 8" X 3½" X 5/8"
8 WEB PLATES 48" X 1⅛" IN PAIRS
8 ANGLES 9" X 6" X 7/8" IN PAIRS
4 WEB PLATES 34" X 5/8"
8 ANGLES 8" X 3½" X 7/8"
CENTER LINE OF ROCKING BENT

FIG. 19.

weight in addition to the weight received from the tower, and for this purpose their size has been increased, as has already been stated, and the center of the foundation has been placed at a point between the two bearings, the distance of which from each bearing is inversely proportional to the respective reactions.

At each end the stiffening truss rests on a rocking bent of smaller dimensions, which rests on a masonry pier.

Each rocking bent at the principal point of support is estimated to weigh, complete, 1 005 000 lbs., and each rocking bent at the extreme ends 480 000 lbs., making, as the total weight of the four rocking bents, 2 970 000 lbs. If to this is added the weight given above, the total weight of the metal work in the suspended superstructure and connections becomes 104 320 000 lbs. This work would all be of structural steel, and in it the strains will nowhere exceed 20 000 lbs. per square inch of gross section under actions of load alone.

The strains in the chords are reversed, and these are further increased by the bending which occurs in the truss under the rise and fall of the cables from the effects of temperature and by the effect of wind. The estimated rise and fall at the center from changes of temperature is 3.3 ft., which, calculated on the same formula as used previously and taking $l = 3\,100$, corresponds to a strain of 3 330 lbs. per square inch.

The bending strain due to the deflection of cables under weight has not been considered in this connection, but in the more refined calculations is considered in connection with all other changes of shape caused by weight in determining the moments on the stiffening truss.

The strains are subject to reversal, and represent, including the effects of temperature, a possible variation of 40 000 lbs. per square inch between extreme positive and negative strains, or 20 000 lbs. in each direction ; this is higher than it is deemed wise to place on ordinary structural steel, and requires a material which, while possessing the toughness of the soft steel preferred for structural purposes, has the strength and high elastic limit of the harder steels. Five years ago such a material would have been considered impossible ; it may now be found in nickel steel containing about 3½% of nickel, a material which will have an elastic limit of about 60 000 pounds per square inch and can be subjected to the reverse strains just referred

to, and under extreme occasional conditions could be worked to at least 40 000 lbs. per square inch without injury. As nickel steel is a comparatively new article, made by a few manufacturers, though it has been adopted to a very great extent by the United States Government in its naval work, it is difficult to learn just what the additional cost ought to be ; apparently it is worth, on the basis of cost, about three-quarters of a cent more per pound than ordinary structural steel, but it has been estimated as costing 2 cents per pound extra, this representing additional mill and shop work, though the latter is very little.

The modulus of elasticity of nickel steel is practically the same as that of ordinary structural steel, and it is proposed to use it only for the principal members of the chords for a length of 2 000 ft. at the center of the bridge, where reversals occur and where wind strains are large. The rivets, splice plates, etc., need not be of nickel steel. The weight of nickel steel in each chord may therefore be taken at 2 000 lbs. per foot, or 8 000 pounds for the four chords, or 16 000 000 lbs. for the 2 000 ft.

The work in the stiffening truss is of a very uniform character, and, considering its great weight, ought to be obtained at a very moderate price per pound ; it is estimated at 4 cents per pound, with an extra allowance for nickel steel.

The total cost of the 4 100-ft. stiffening truss, supporting bents, etc., may therefore be taken as follows:

104 320 000 lbs. at 4 cents....................	$4 172 800
16 000 000 " nickel steel, at 2 cents extra...	320 000
Total	$4 492 800

Shore Piers.

To sustain the ends of the stiffening truss two additional piers will be required. These piers should be founded on rock, but would be piers of ordinary dimensions, and, though large, would present no special difficulties of construction. On the plans, Fig. 1, they are shown with the masonry finishing at an elevation 60 ft. above mean high water, which is probably higher than necessary, and the depth to rock is assumed to be 80 ft. below mean high water. The piers are assumed to be 20 ft. wide and 120 ft. long on top, the masonry to start

at the water level and to be founded on a caisson and surmounted by a timber crib filled with concrete, the whole foundation being 35 ft. wide, 135 ft. long and assumed as 80 ft. high. The cost of these piers is estimated as follows:

6 000 cu. yds. masonry at $25	$150 000
378 000 cu. ft. foundation at 60 cents	226 800
Total	$376 800

The cost of the two piers, one at each end, would then be $753 600.

Wind Pressure.

The wind surface per lineal foot presented by one-half of one web, the lower chord and the floor system is 11.35 sq. ft., and the wind surface presented by the upper half of the web and the upper chord is 7.77 sq. ft. As the trusses are 100 ft. apart, the area of the trusses should be doubled, but the floor comes so near to being solid that it need not be doubled. The total surface presented to the wind which must be resisted by the top laterals is therefore 15.54 sq. ft. per lineal foot, and the total surface presented to the wind which must be resisted by the bottom laterals is 19.12 sq. ft. per lineal foot. To the latter should be added the area of a passing train, which is equivalent to 8 ft. above the bottom chord, thus making the total wind surface to be provided for 27.12 sq. ft. per lineal foot. On a basis of 30 lbs. per square foot the total wind pressure to be resisted is—

Top lateral system	466 lbs.
Bottom lateral system	814 "
Total	1 280 "

For the calculations, these figures have been slightly varied, and the top laterals are proportioned to resist a wind pressure of 500 lbs. per lineal foot and the bottom laterals a wind pressure of 750 lbs. per lineal foot.

There is no probability that anything like these wind strains will ever be reached over the whole length of the span, though considerably greater pressures may occur for limited lengths. To reduce these amounts, however, would be a departure from established practice.

The wind pressure would be transferred to the towers where the stiffening truss passes the towers, by horizontal cables, these cables reaching from each chord to the outer posts of the towers, the cables clearing the inner posts and being long enough to provide for the longitudinal motion of the trusses without overstraining. These horizontal cables would be tightened under strain so that they would always stiffen the trusses. A portion of the wind strain would undoubtedly be taken by the transverse bracing of the rocking bent. Furthermore, the continuity of the truss beyond the rocking bent would reduce the equivalent length of the central span. In calculations this reduction has been assumed to be about 50 ft. at each end, though this is undoubtedly much less than it would really be. On this basis the bending strain produced by wind in the bottom chords will be—

$$\frac{3\,000^2 \times 750}{8 \times 100} = 8\,437\,500$$

This corresponds to about 14 000 lbs. per square inch on the 600 sq. ins. of the bottom chord, and gives a deflection calculated as above of 8.75 ft. Should this occur when there is a maximum strain in the chords from the passage of trains, a condition which would probably not take place more than once in a century, the chords might possibly be strained to 34 000 lbs. per square inch. With nickel steel this is perfectly safe.

In these calculations it is assumed that the chords of the stiffening truss are the only longitudinal members, which is by no means correct, as the sixteen stringers will act as auxiliary chords in the wind system.

There is also another element which materially reduces the effect of wind. To produce the above-mentioned strains in the chords, the whole suspended superstructure must move laterally 8.75 ft. This involves swinging the main cradled cables and raising the center of gravity of the suspended superstructure, a lateral movement of 8.75 ft. corresponding to a lift of 0.075 ft. or 1 vertical to 117 horizontal. As the suspended superstructure weighs 27 000 lbs. per lineal foot, this will require a horizontal force of 230 lbs., so that before this deflection can occur the actual wind pressure must be about 1 000 lbs. per lineal foot on the bottom chord.

Rivet Strains.

While plans showing the details of riveting have only been prepared as a study, it has been necessary to form some basis on which they should be proportioned, especially as owing to the magnitude of the structure and the large relative dead loads, the unit strains vary from those ordinarily used. The simple rule has been followed that the bearing stress on each rivet should be considered equal to the stress allowed in the gross section of the member, and the shearing stress should be limited to one-half the stress allowed in the gross section of the member; this may be expressed differently by stating that the bearing surface of the rivets should not be less than the gross section of the member, and the shearing section of the rivets should be double the section of the member. Where nickel steel is used, the number of rivets is increased one-half, the bearing surface of the rivets being made 50% greater than the gross section of the member and the shearing section of the rivet three times the gross section of the member.

Erection.

The erection of the stiffening truss and suspended superstructure is a comparatively simple thing. The back spans, 500 ft. each, would be erected on falsework in the usual manner, which could be put in without difficulty as it is in a protected position back of the pierhead lines. The projections from the rocking bents to the suspenders would be built out as cantilevers, all of which could be done without trouble.

The suspended superstructure proper would be handled in a different way. The floor beams would be put in position first; they would be brought to the bridge site on barges and raised into position, each beam being hung from the suspenders as fast as raised. The stringers would be put in and riveted up as the floor beams are erected, so that when all the floor beams are up, a reasonably stiff floor would be ready to work on; this portion of the work could be done very rapidly, as each of the 84 floor beams could be handled independently.

When the floor beams are in place and the floor system riveted up it could be covered with planks and form a working platform. The bottom chords of the stiffening truss would then be put in place and riveted up, the horizontal rivets being driven by power, and the

vertical rivets, which are of less importance, by hand. The only matter which would require special attention would be to see that a uniform distribution of weight was kept at all times, and this is a matter of discipline rather than of difficulty. As soon as the bottom chord is riveted the lower half of the webs would be erected and this would be followed with the upper half, after which the top chords would be put on and the top lateral system erected. The broad floor would form a platform on which any desirable system of travelers could be run and the opportunities for work would be as good as in a shop, except that there would be no roof.

The total weight of suspended superstructure which must be erected in suspension is about 34 000 tons. The speed with which it could be handled would depend entirely on the number of men and the amount of plant employed.

Estimate.

The work has been described in the manner in which the design has taken shape, and the cost of each separate portion has been estimated in connection with this description. In execution the work would necessarily be differently divided and may properly be grouped under the respective heads of substructure and superstructure.

Under these heads the cost may be stated as follows:

Tower foundations	$5 456 000	
Anchorages	2 642 800	
Shore piers	753 600	
Substructure		$8 852 400
Metallic steel towers	$1 912 000	
Wire work, etc	4 866 149	
Suspended superstructure, etc	4 492 800	
Superstructure		11 270 949
Total		$20 123 349

For purposes of inspection an elevator ought to be placed in each of the four towers, and two of these elevators ought to be of sufficient size to accommodate passengers; $100 000 should be reserved for these elevators and the various appliances in connection with them.

The ornamental work on top of the towers, with provisions for lighting, etc., would cost another $100 000.

The structure, with a 10% allowance for contingencies and engineering, would cost about $22 500 000, or somewhat less than $5 500 a foot for the 4 100 ft. of suspended superstructure.

By making some modifications in the plan, among which may be mentioned allowing a greater flexibility under extreme conditions and reducing the depth of the stiffening truss, the cost could probably be reduced to about $20 000 000.

Time.

The time it would require to construct such a bridge would depend largely on the resources of the company building it. If everything were in readiness, both legally and financially, it ought to be built in five years. The foundations for the towers could be conducted simultaneously and completed in two years. The steel towers could be erected in another year. The anchorages and shore piers could be completed before the towers are done. The cables, being already manufactured, could be erected in one year. The back spans and projecting cantilevers could be raised while the cables were being put in position. The suspended portion of the superstructure, 2 800 ft., could be erected in one year. This allows two years for the erection of the metallic towers and the placing of the cables, which could probably be materially reduced. Five years would therefore appear to be enough for the construction of this bridge.

APPENDIX A. TEST OF WIRE ROPES, MADE AT U. S. ARSENAL, WATERTOWN, MASS., MAY 2D–4TH, 1895.

In the straight wire ropes the elongation was measured on 100 ins.; in the coiled wire ropes, on 200 ins.

In all instances, except Nos. 8 269 and 8 279, the method of testing was, after putting on 50 000 lbs. per square inch, to measure the elongation, then reduce the strain 10 000 lbs., then increase it successively by 10 000 lbs. amounts until it was 10 000 lbs. more than it had been before, measuring the elongation at each change of strain. The elongation given in this table is the last elongation measured before the strain was increased more than 10 000 lbs. above that for which the elongation had been previously taken.

Test No. 8 275 was left under a strain of 60 000 lbs. per square inch for 16½ hours, at the end of which time this strain was reduced by

Test of Steel Wire Ropes.

Character of Rope.	Straight Wire.				Coiled Round Wire.				Patent Locked Wire.			
Character of wire	Special Steel.		Plow Steel.		Special Steel.		Plow Steel.		Special Steel.		Plow Steel.	
Number of test...........	8 269	8 279	8 271	8 274	8 270	8 278	8 273	8 275	8 272	8 280	8 276	8 277
Strain per Square Inch.	Percentage of Elongation above that Produced by Initial Strain of 10 000 lbs. per Square Inch.											
50 000 lbs................	0.1525	....	0.1834	0.1803	0.2588	0.2752	0.2257	0.2355	0.2735	0.2525	0.2742	0.2710
60 000 "	0.1994	....	0.2255	0.2195	0.3190	0.3353	0.2794	0.2817	0.3274	0.2973	0.3286	0.3259
70 000 "	0.2405	....	0.2651	0.2604	0.3968	0.4059	0.3351	0.3345	0.3862	0.3553	0.3937	0.3877
80 000 "	0.2889	....	0.3070	0.3032	0.4674	0.4811	0.3980	0.3937	0.4573	0.4229	0.4673	0.4611
90 000 "	0.3382	....	0.3478	0.3476	0.5509	0.5637	0 4676	0.4575	0.5424	0.5207	0.5537	0.5479
100 000 "	0.4409	....	0.3890	0.3930	0.5930	0.6724	0.5345	0.5209	0.5862	0.6007	0.5496	0.6555
Ultimate strength........	150 000	146 640	188 980	187 360	148 120	140 000	187 230	177 690	133 180	131 970	142 220	176 850

about 330 lbs. per square inch, when the tests were resumed; the elongations given were all measured subsequently to this rest.

Test No. 8 280 was left under a strain of 60 000 lbs. per square inch for 39 hours, during which time the strain was reduced about 5 000 lbs. per square inch, when the tests were resumed; the elongations given were all measured subsequently to this rest.

Each of the round wire ropes was formed of 37 No. 8 wires. Each of the locked ropes was formed of 62 wires, of which the central one was round, the intermediate wires square and the outer layer of special lock section. The straight wire ropes were wrapped with fine soft wire.

In the cases of the two ropes which were left under strain, one over night and the other over two nights and an intermediate Sunday, the strains were reversed back and forth between 50 000 and 60 000 lbs. several times when testing was resumed, and the observations under these conditions were specially interesting and valuable. They were as follows:

Strain per Square Inch.	Elongation in 200 Ins.	
	Number of Test, 8 275.	Number of Test, 8 280.
60 000 lbs.	0.5510	0.5852
50 000 "	0.4711	0.5051
60 000 "	0.5511	0.5853
50 000 "	0.4711	0.5051
60 000 "	0.5513	0.5851
50 000 "	0.4711	0.5051
60 000 "	0.5512	0.5852

These show an extraordinarily uniform modulus of elasticity of 25 000 000 lbs., and show how uniformly this rope may be depended upon for action in a structure, even though there be a material difference in the quality of the wires.

Five wires were taken from two of the straight wire cables, one being of special steel and the other of plow steel. The samples taken from the special steel showed an average strength of 172 588 lbs. per square inch, and an average reduction of 44.2 per cent.; the plow steel showed an average strength of 226 504 pounds per square inch and an average reduction of 45.7 per cent. In the case of the plow steel one wire was nicked before testing; its strength was fully up to the average of the others, but its reduction was so much less that it has been excluded in calculating the average reduction.

The fractures always occurred first in the outer wires and the ropes evidently failed to develop their full strength owing to defects in sockets, which were not as well finished inside as they should have been.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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PAPERS.

EXPERIMENTS ON THE PROTECTION OF STEEL AND ALUMINUM EXPOSED TO SEA WATER.

By A. H. SABIN, Assoc. M. Am. Soc. C. E.

TO BE PRESENTED NOVEMBER 4TH, 1896.

In February, 1895, the author, by permission of the Navy Department, suspended a cage containing twenty iron plates coated with various preservative coatings in the sea water in the Brooklyn Navy Yard. At the expiration of six months it was found that by some accident the cage and all the plates had been lost. Arrangements were then made for another and more carefully conducted test, and in making these arrangements the author was assisted by Naval Constructor F. T. Bowles, to whom he takes this opportunity of expressing his appreciation and thanks. Without his co-operation it would have been impossible to carry out the experiments. The work of preparing and applying the coatings was done by Edward Smith & Company, of New York City, who paid all the expenses incident to the whole work, and the aluminum plates were furnished free of charge by the Pittsburgh Reduction Company.

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

It was desired especially to learn the protective capacity of various varnishes and of what are known as enamel plates, which are pigments ground in varnish.

The ordinary oil and resin varnishes are made by compounding certain resins (of which those selected for these experiments are Kauri, Zanzibar and Manilla, and the resinous mineral known as gilsonite) with various proportions of refined linseed oil, and these oil and resin compounds are then thinned with spirit of turpentine, which is commonly regarded as a vehicle, so that the essential differences in varnishes are due chiefly to the kinds of resin used and the proportion of oil. For convenience, it is customary to assume 100 lbs. of resin as the unit, and with this compound 8 galls. of oil for one kind of varnish, or 12 galls. for another, or 20 galls. for another, or 30 galls. for another; and it was believed that for the purpose of these experiments these four types of varnishes, commonly spoken of as 8, 12, 20 and 30-gall. varnishes, were sufficient. It was also regarded as desirable to know what resins were most suitable; hence there were prepared such series of varnishes from Kauri, Zanzibar and Manilla resins, and an 8-gall. Kauri varnish is designated as 8 K., an 8-gall. Zanzibar as 8 Z., an 8-gall. Manilla as 8 M., and so on.

To make what are known as enamel paints, certain pigments are ground in these varnishes, and it was thought desirable to ascertain what effect the character of the pigment has on the durability of the paint. Hence, in some cases, flake white, which is pure white lead, was used; in others, white zinc; and in others, pigments thought to be chemically inert, as ultramarine blue and chromium oxide, and also a very permanent red pigment known as flamingo red, the exact composition of which is not known.

Inasmuch as it has been believed that the process of baking adds to the durability of these coatings, in most cases duplicates were prepared, one of which was baked and the other allowed to dry at the ordinary temperature.

Besides these varnishes and enamel paints, plates were coated with ordinary red lead in oil, with two kinds of iron oxide paints in oil, with an iron oxide paint mixed in a shellac compound after a formula furnished by Naval Constructor Bowles, with ivory black in japan, with Edward Smith & Company's "Durable Metal Coating," which is a varnish in which a considerable amount of gilsonite has been sub-

stituted for resin, and with the "Sabin Process" enamel, which has been used on some of the most important hydraulic work done within the past few years. It is hoped that a careful study of the effect of sea water on these various coatings, part of which were applied to steel and part to aluminum plates, will lead to important advances in the knowledge of the subject.

The steel plates used were ordinary boiler steel about $\frac{3}{16}$ in. thick, purchased from a well-known firm of boiler makers. In all cases where two steel plates were coated with the same preparation, the one bearing the odd number was dried at the ordinary temperature and the one bearing the even number was baked at a temperature of 215° to 240° Fahr. for four hours or longer; except that all the "Sabin Process" pipe coating enamels were baked two hours at 400° to 450° Fahr. Each plate was stamped with a number before coating. The following table gives the coating applied:

STEEL PLATES.

No.	Coating.
1 & 2	Flake white in 20 K.
3 & 4	Flake white and white zinc, equal parts in 20 K.
5 & 6	White zinc in 30 K.
7 & 8	White zinc in 20 K.
9 & 10	" " in 12 K.
11 & 12	" " in 8 K.
13 & 14	" " in 30 M.
15 & 16	" " in 20 M.
17 & 18	Flake white in 8 M.
19 & 20	White zinc in 30 Z.
21 & 22	" " in 20 Z.
23 & 24	" " in 8 Z.
25 & 26	Flamingo red in 20 K.
27 & 28	Ultramarine blue in 20 K.
29 & 30	Chromium oxide in 20 K.
31 & 32	Durable metal coating.
33 & 34	" " "
35, 36, 37 & 38	"Sabin Process" pipe coating enamel.
39	Ivory black in japan.
40	Red lead in oil.

41..............Prince's metallic paint (oxide of iron) in oil.
42..............Purple oxide of iron in oil.
43 & 44........No pigment, 8 K. varnish.
45 & 46.........No pigment, 12 K. varnish.
47 & 48......... " " spar varnish.
49 & 50......... " " 30 K. varnish.
51 & 52......... " " wearing body varnish.
53.............Iron oxide in shellac mixture.
54..............Parahydric coating.

When these plates were removed from the water on July 29th, 1896, after six months' immersion, they were immediately inspected by Naval Constructor Bowles, Foster Crowell, M. Am. Soc. C. E.; William Barclay Parsons, M. Am. Soc. C. E.; Mr. S. V. V. Huntington, Manager of Edward Smith & Co.; James C. McGuire, Jun. Am. Soc. C. E., and the author. The plates were afterward removed to the author's laboratory, and, after an interval of a month, were carefully examined, with the following results:

1. Good ; first-rate condition.

2. Good, but some small marginal blisters. No corrosion.

3 & 4. Like 1 and 2. Coating could be peeled off with a knife when first taken from the water.

5. Very thin near the edges; some marginal blisters.

6. Same; coating brittle where very thin, elsewhere tough; no corrosion.

7. Like 5. Fifteen or twenty small rust spots where the coating was very thin. Brittle.

8. Good condition; no blisters, but coating brittle; not easily scraped off when wet.

9. Hard and brittle, but not completely removed by scraping while wet. A large number of pin-hole rust spots on one side.

10. Good; no blisters, but hard and brittle, especially where thin.

11. Hard and brittle; no blisters; not easily removed by scraping while wet. The outer coat separated from the under coat when scraped, leaving the latter on the metal.

12. Some small blisters and rust spots on one side. Hard and brittle.

13. Hard and brittle, very many minute rust spots. General condition poor.

14. Could be completely scraped off with a knife when wet. Very little rust. Both 13 and 14 were tough and good where the coating was very heavy, brittle where thin.

15. Thin. General condition good, except along the margins, where there was some rust. Brittle.

16. Coating thicker on one side than the other. The thicker film gave good protection, but the other side was brittle and showed numerous rust spots.

17. Coating badly decomposed, the action taking place from the outer surface. Not much corrosion.

18. Some marginal blisters, but general condition pretty good; much better than 17.

19. First-rate condition, tough and adherent; not completely scraped off with a knife when wet; rather thin along edges.

20. General condition perfect, but could be scraped off when wet.

21. Good condition, but thin and brittle near edges; not easily completely removed.

22. Same, but coating could be scraped off when wet.

23 & 24. Thin, brittle, many rust spots; poor condition.

25 & 26. Many rust spots; general condition bad.

27. Not much rust, but many blisters; condition not good.

28. Better than 27, but very many small blisters.

29 & 30. About alike; very many small rust spots.

31 & 33. Some blisters along the margins where the coating was thin; elsewhere the coating was all right; could be scraped off when wet.

32 & 34. Same as 31 and 33, except that there was much more blistering along the edges. Not good.

39. Very bad; rusty all over.

49. A good many small rust spots, but no general corrosion. Coating considerably decomposed; could be scraped off completely, but not very easily. General condition fair.

All the pipe coating enamels were perfect.

Plates 41 to 54 were in a separate cage, which was destroyed by an accident after about three months' immersion, and all the plates were lost. This was very unfortunate, as these would have shown some well-known oil paints in comparison with the others, but the test will be repeated.

Thirty aluminum plates, coated with various paints and enamels, were removed from the sea water in the Brooklyn Navy Yard, July 29th, 1896, after immersion for six months.

The composition of these plates was as follows:

Series I.—Ninety-nine and one-half per cent. pure aluminum.

Series II.—Ninety-eight per cent. aluminum and 2% copper.

Series III.—Ninety-eight per cent. aluminum (the quality known as commercially pure aluminum).

Series IV.—Ninety-three per cent. aluminum and 7% copper.

Series V.—Seventy-five per cent. aluminum, 20% zinc, 3% copper, 1% iron.

These plates were numbered from 101 to 130, and were coated as follows:

I.	II.	III.	IV.	V.	
101	107	113	119	125	"Sabin Process" pipe coating enamel, baked.
102	108	114	120	126	Durable metal coating, one side baked.
103	109	115	121	127	Ultramarine blue, one side; flamingo red, one side; ground in varnish, not baked.
104	110	116	122	128	White zinc ground in varnish, one side baked.
105	111	117	123	129	Chromium oxide ground in varnish, one side baked.
106	112	118	124	130	Edward Smith & Co.'s spar varnish, no pigment, one side baked.

The varnish in which the ultramarine blue, flamingo red, white zinc and chromium oxide were ground was composed of 100 lbs. Kauri resin to 20 galls. linseed oil, thinned with turpentine. The chromium oxide was the anhydrous oxide made by the ignition method, and was of commercial quality, not chemically pure. The baked coatings were baked about four hours at 215° to 240° Fahr., except that the "Sabin Process" pipe coating enamel was baked two hours at 400° Fahr.

The condition of each plate is given in the following statement:

Series I.

101. Perfect.

102. Baked side, perfect. Unbaked side, three blisters $\frac{3}{4}$ in. diameter. No general corrosion or roughening. The surface of the paint had lost its gloss. The coating was good on the edges of the plates.

103. Ultramarine blue. Showed roughening of coating, numerous pin head blisters, no corrosion to speak of.

Flamingo red. General condition good, except near edges of plate, which showed blisters over a surface about half an inch wide and one-fifth the marginal distance; very little corrosion.

104. Baked side. About 2 sq. ins. in one place half covered with small blisters. No corrosion.

Unbaked side. First-rate condition.

105. Baked side, one blister, 1 x $\frac{1}{2}$ in.; otherwise first rate. No corrosion. Unbaked side all right.

106. Both sides perfect.

Series II.

107. Perfect.

108. Baked side, one blister, $\frac{3}{8}$ in. diameter.

Unbaked side perfect.

109. Blue and red about the same as 103, except that about twice as much surface was blistered. General condition good.

110. Baked side badly blistered in spots along the edges, amounting to about 6% of the total surface of the plate. Some corrosion under these.

Unbaked side all right, except that about 1% of the surface showed pin-head blisters along a strip about $\frac{1}{2}$ in. wide on one edge of the plate.

111. Baked side showed four central $\frac{3}{4}$-in. blisters, numerous marginal ones about $1\frac{1}{2}$% of plate. Very little corrosion.

Unbaked side in first rate condition.

112. Baked side, two central blisters 2 sq. ins. and 4 sq. ins., and nearly all the margin $\frac{1}{2}$ in. wide. Considerable corrosion. Otherwise perfect protection and high luster.

Unbaked side, two central blisters $\frac{1}{2}$ sq. in. and 1 sq. inch.

Slight marginal corrosion. Coating evidently thin on edges.

Series III.

113. At one corner evidently a break in the coating let in water and caused a blister of about 2 sq. ins. Coating rather overbaked and brittle; elsewhere perfect.

114. Baked side perfect.

Unbaked side tough and adherent, except one small spot near the middle of the plate, which looked as if the coating had been broken, and where corrosion had begun.

115. Blue and red about alike. No decided blisters, but coating itself showed some signs of decomposition, especially the blue, which had a rough surface.

116. Both sides in good condition, but showed some signs of incipient blistering about the edges.

117. All right on both sides.

118. Both sides quite perfect.

Series IV.

119. At several places about the corners of the plate single blisters, some of which were as large as 3 sq. ins., had formed. These appeared to be due to the fact that the coating was overbaked and had been cracked at the corners by the supporting framework, and galvanic action had ensued on the penetration of the sea water. This was facilitated by the 7% of copper in the alloy. The remainder of the plate was perfect.

120. Baked side showed three blisters of about 1 sq. in. each and some corrosion under these; otherwise all right.

Unbaked side perfect.

121. Blue and red about alike; about 30% blistered and corroded.

122. Pin head blisters along the edges; general condition all right.

123. Baked side all right.

Unbaked side, seven or eight small blisters, but no corrosion. General condition good.

124. Both sides badly blistered and corroded along the edge, about 10% of the surface. Where not blistered, all right.

Series V.

125. Coating brittle and certainly overbaked. Badly blistered along the edges. In all cases of blisters under pipe coating enamel, the blisters were continuous and start from the edge.

The middle of the plate was all right.

126. Baked side badly blistered along the edge, 6% or 8% affected. Unbaked side slightly blistered, chiefly along one edge; condition otherwise good. No corrosion.

127. Blue. Considerably blistered along the edges, in pin head blisters mainly. Little corrosion.

Red. About the same, but some large marginal blisters. The red had a smooth surface, but the blue was rough.

128. Baked side, nine or ten blisters of some size ($1\frac{1}{2}$ ins. diam.), and considerable corrosion. Remainder of surface good.

Unbaked side. About 1% of the surface, near the edges, with small blisters showing some corrosion. The rest of the surface all right.

129. Baked side. A large number of groups (about 1 in. diam.) of small blisters. No corrosion.

Unbaked side. About the same, but not as bad.

130. About like 124.

The pigment mentioned as flamingo red is supposed to be a mixture containing some coloring matter derived from coal tar, and is reasonably permanent in the air. In these tests it became dark and mottled.

The baked surfaces of those plates which had one side baked were in all cases harder and more glossy than the other sides, after the test was made. It should be observed, however, that while these coatings are all at present hard and firm, when they were first taken from the water they were much softer and could be more easily scratched or scraped off, with the exception of the pipe-coating enamel, which was exactly as it was when it was put in the water. Even the luster was not affected, and the smooth plates coated with it are like a mirror.

On all the plates, except those coated with pipe-coating enamel which was applied by dipping, the coating is much thinner for about an inch along the edges of the plates than it is on the central portion. This fact has been called to the attention of the workmen who painted the plates, and is said to result from the method employed in applying the paint with a brush. In future experiments, care will be taken to avoid this. Probably four-fifths of the corrosion occurred along this marginal strip.

The more nearly pure the aluminum, the less it seems to need protection. The series which contain large amounts of copper or zinc are the most difficult to protect; corrosion seems to progress rapidly when

the sea water gets the slightest admission, and it throws off the coating, no matter how impervious the latter may be.

These plates were suspended in an open oaken cage or rack, the plates being in a horizontal position, one above another, about 2 ins. apart. They fitted loosely in the rack, and each plate was supported at the four corners. The rack was suspended from a float, and was 6 ft. or so below the surface of the water.

In fitting these plates to the wooden frames, they were originally tight, but became loose as the water swelled the wood. In transporting them to the Navy Yard, putting them again in place, and the subsequent handling, it is quite possible that scratches may in some cases have been made in the coatings, which would account for some of the blisters on plates which were otherwise perfectly protected. Greater care will be given to these details in the future.

Other experiments indicate that there is probably considerable sewage in the water, as sulphides are present in appreciable quantity. Something in the water also discolored the white zinc used, but did not act except superficially.

White zinc appears to be the least acted on of any pigment used in this test. The durable metal coating gave excellent results. When first taken from the water, however, this coating was somewhat soft, though extremely tough and elastic, and could then have been scraped off. After drying, this was impossible.

The most satisfactory coating is the pipe-coating enamel, which was baked on; and it is probable that if it had not been for the accidental overbaking of some of the plates, a condition difficult to avoid in using a small oven though easy to regulate in a large one, all the plates thus coated would have been perfectly preserved. The other baked coatings did not do so well. It appears that an extremely high degree of elasticity is very essential in these tests.

In the foregoing notes, where it is said that there was "no corrosion," it is meant that there was no appreciable roughening of the metallic surface, which was bright when the paint was removed. Where corrosion is noted, it is meant that a deposit of oxide was found under the paint. In all cases of blistering there had been a little corrosion.

It is proposed to replace a considerable number of the plates, both steel and aluminum, for a further six months' test.

The author has at present no explanation to make of the results so far presented, but makes one or two suggestions. Charles B. Dudley, M. Am. Soc. C. E., has a theory that varnish is so constituted as to have a part of the oil which it contains in chemical combination with the resinous material, and a part of the oil free. If this theory is correct, it would be reasonable to suppose that the longer the oil and resin are heated together in the process of varnish making, and the higher the temperature employed, the more complete will be the combination of oil and resin, and the less free oil will remain. Now, for certain reasons it is not practicable to heat 8-gall. and 12-gall. varnishes nearly so much as 20-gall. and 30-gall. varnishes; and if one action of sea water is to dissolve the uncombined oil, it is plain that the varnishes which contain the most oil, but are most thoroughly combined, will suffer less than those in which the proportion of oil is less. This would explain the singular fact that while it appears both by these tests and by other and more general experience that a suitable combination of oil and resin has greater protective action than oil alone, yet the smaller the proportion of resin, the more durable the compound. It may be objected that oxidized linseed oil is itself a very permanent substance, but, while this is so, it is also true that it is easily dissolved by alkalies, and even by water containing ammonia, and it is quite possible that it may be rather easily soluble in sea water. Further experiments are needed on this point.

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PAPERS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

A RESURVEY OF THE WILLIAMSPORT DIVISION OF THE PHILADELPHIA AND READING RAILROAD.*

By GEORGE D. SNYDER, Assoc. M. Am. Soc. C. E.

ABSTRACT.

In 1890 the author was retained by the Philadelphia and Reading Railroad Company to make a survey of its line between Port Clinton and Newberry Junction, a distance of 125 miles. From Port Clinton to Sunbury the road has heavy grades and sharp curves, while from Sunbury to the end of the division the grades are light and the curves easy.

The survey was made to establish a working center line and to introduce transition curves where practicable. All physical features of the ground within a short distance on each side of the center line were located, and data obtained for establishing the right-of-way and property lines. A complete line of levels was to be run over the road, and working grades established for the track, but as the survey was not completed, this work was not finished. From the data obtained by the survey, maps and profiles of the line were prepared on which were

*This paper was accepted by the Committee on Publication for filing in the Library of the Society and will not be published in full. It is not open to discussion. It may be examined in the Library, and further information concerning its contents may be obtained by application to the Secretary.

to be recorded all subsequent changes in tracks, alignment and right-of-way. This work, like the leveling, has never been finished.

In running the center line the tangents were established first. If the point of intersection was accessible, the intersection angle and the external secant were measured. With these data the degree of the curve was obtained which would fit between the two tangents and strike the apex of the curve. If an error of one to five minutes was allowable in the degree of curvature the latter was obtained on the slide rule by the formula $R =$ external secant $\div$ tan. $\frac{1}{2} I$ tan. $\frac{1}{4} I$, where R is the radius, and I the intersection angle. This formula is readily solved by the slide rule, which was employed largely in the computations made during the survey.

It was found inadvisable to run the tangents to an intersection where the ground was broken, uncleared or steep, as the measurements on the comparatively level roadbed were more accurate. In such cases the degree of the curve was obtained by holding a tape against the inside of the outer rail at points 62 ft. apart. The length in inches of the ordinate to the rail at the middle of the chord gave the curvature at that point in degrees. The mean of several measurements was assumed to be the degree of the curve. The location of the P. C. was then judged by the eye and a trial curve run, without putting in any stakes, to the end of the curve or until the trial line left the roadbed. In the latter case the distance D, from the trial line to the proposed center line at the last station was measured, and the distance, S, necessary to shift the P. C. was obtained by the formula $S = D \div \sin. A$, A being the total angle to the last station. By means of the slide rule, this shift can be ascertained readily, as well as the amount it will throw the line from the trial curve at each station. In this manner a new P. C. can be obtained and the curve run around to the next tangent.

When the degree of curvature found by means of the 62 ft. chord proved to be in error, the trial curve was generally inside or outside the track at its apex. Sometimes it was found that both the trial P. C. was incorrectly located and the degree of the trial curve was wrong. The data for changing the degree of the curve and shifting the P. C. were furnished by simple computations on the slide rule. Having run the trial curve for eight stations, say, the slide rule was set as explained previously for a shift of the P. C. to make the eighth

trial station strike the center line; the same setting also gave the distance this shift would move the fourth or middle trial station. The difference between this distance and the distance the fourth trial station had diverged from the center line gave the amount of change in the external secant necessary to make the curve fit the track. The degree of the new curve was then found by the slide rule. To find how far this new degree of curve would diverge from the trial curve and the track, the formula $O = \frac{7}{8} n^2 D$ was used, in which O is the offset from the tangent or from one curve to another, n is the number of 100-ft. stations, and D is the degree of the curve, or the difference in degree of two curves. This formula furnishes the data necessary to complete the location, and is particularly well adapted to the slide rule.

Transition curves were run by means of Froude's formula * $O = L^2 \div 24\ R$, in which O is the main offset from the circular curve to the tangent, L is the length of the transition curve, and R is the radius of the circular curve. By substituting $5730 \div D$ for R, the formula becomes $O = L^2\ D \div 137520$, where D is the degree of the curve. This curve is practically a cubic parabola having properties which enable all the computations involved in using it to be made on the slide rule. The transition curve bisects the main offset at the P. C., and is itself bisected by the offset line at this point. The offsets to the transition curve from the tangent or the circular curve are as the cubes of the distances, and the deflection angles to points on the transition curve are as the squares of the distances.

In the field, a simple curve which would fit the track was first found, and the offset was either assumed or calculated on the slide rule from an assumed length. If the tangents were offsetted and the same degree of curvature used as before, it would throw the whole curve toward the center a distance about equal to the offset. As this would generally throw the track off the road-bed, the usual practice was to sharpen the curve enough to make its apex strike the same place as before. To offset this the external secant of the new curve was reduced by an amount equal to O tan. $\frac{1}{2}\ I$, I being the intersection angle of the tangents. This distance was ascertained on the slide rule. From the point of the transition curve to the P. C., the offsets to the transition curve were set off from the tangent. The transit was then

* See Rankine's "Civil Engineering," p. 652.

placed over the P. C. and the remaining points of the transition curve located by offsets from main curve, the same offsets as before being used, but in an inverse order and an opposite direction.

The intermediate points on the transition curve can also be set by deflection angles. The total angle between the tangents at the beginning and end of the curve is equal to the total angle for the circular arc it replaces, and is obtained by multiplying the degree of the circular curve by half the length of the transition curve. One-third of this product is the deflection angle from the original tangent to the point where the transition and circular curves join. As the intermediate angles are as the squares of the distances, they are obtained readily on the slide rule. The offset method was generally found preferable, except where the transition curve is quite long. The same principles were applied in running one of these curves between two circular arcs.

The advantages of this method are as follows: The engineer is not limited to a certain number of curves with fixed lengths and offsets, as in methods where tables are used, but practically any length of transition curve can be used with any degree of curve. The calculations are all simple, and can be performed readily on the slide rule. The method of staking out and running the curve does not differ materially from ordinary curve work, and any transitman can learn the principles on which the method is based. It does not require complicated methods of plotting and keeping field notes. On original location, it adds nothing to the cost of the field work, as the transition curve need not be run, but merely provided for by making the necessary offsets at each P. C. and P. T., leaving the curve to be run in whenever necessary during construction, which will not be generally until track is to be laid. It will be found in numerous cases to facilitate location, because a long curve need not be rerun merely because it does not quite strike the terminal tangent, as any slight deviation will merely make the offset of the transition curve correspondingly greater or less.

Engineers who have been engaged on rerunning old locations know that the time spent by a party thus employed in actually marking the center line is but a small part of their working hours, and that much of their time is spent waiting for the man in charge to make the necessary calculations. To reduce to a minimum the delay caused

by these numerous computations, the author began the use of the slide rule. It was first employed in checking results, and, as confidence in it increased and a knowledge of its possibilities and limitations was obtained, some calculations were undertaken on it alone, and finally practically all of them, with the result that the party had little idle time.

The plotting was done very carefully. The maps were drawn on a scale of 1 in. to 50 ft., one-half mile being on each sheet. A longitudinal section of each bridge was shown, on which the general dimensions of the structure and its members were marked. The adjustment of the right of way was very difficult. The land was of slight value when the road was built, and little care was taken in drawing up the deeds. Many of them merely granted a right of way so many rods wide through a certain property in a certain township. As many of the deeds were drawn up in 1830, and there had been numerous changes in the ownership of adjoining properties since then, the title of nearly all the real estate along the line had to be traced back from forty to sixty years. All information relating to the right of way was tabulated on separate sheets, and a reference number on each separate purchase on the map showed on which sheet this information could be found. Index maps on a scale of 1 in. to 2 000 ft. were also prepared, as well as sketch maps of each train dispatcher's district. On the latter were indicated the main track, branches and all sidings, showing the number of cars each would hold.

The paper is accompanied by fifteen drawings, two photographs and an appendix giving slide rule settings applicable to field calculations on a railway survey.

Vol. XXII. OCTOBER, 1896. No. 8.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publication.

CONTENTS.

SOCIETY AFFAIRS.

PAPERS.

The price of publications is as follows: Proceedings, $6 per annum; Transactions, $10 per annum. Postage will be added when they are sent to foreign countries.

American Society of Civil Engineers.

OFFICERS FOR 1896.

President, THOMAS C. CLARKE.

Vice-Presidents.

Term expires January, 1897:	*Term expires January*, 1898:
DESMOND FITZGERALD,	WILLIAM R. HUTTON.
BENJAMIN M. HARROD,	P. ALEXANDER PETERSON.

Secretary, CHARLES WARREN HUNT.

Treasurer, JOHN THOMSON.

Directors.

Term expires January, 1897:	*Term expires January*, 1898:	*Term expires January*, 1899:
WILLIAM H. BURR,	AUGUSTUS MORDECAI,	GEORGE A. JUST,
JOSEPH M. KNAP,	CHARLES SOOYSMITH,	WM. BARCLAY PARSONS,
BERNARD R. GREEN,	GEORGE H. BENZENBERG,	HORACE SEE,
T. GUILFORD SMITH,	GEORGE H. BROWNE,	JOHN R. FREEMAN,
ROBERT B. STANTON,	ROBERT CARTWRIGHT,	DANIEL BONTECOU,
HENRY D. WHITCOMB.	FAYETTE S. CURTIS.	THOMAS W. SYMONS.

Assistant Secretary, JOHN M. GOODELL.

Standing Committees.

THE PRESIDENT OF THE SOCIETY IS *ex-officio* MEMBER OF ALL COMMITTEES.

On Finance:	*On Publications:*	*On Library:*
JOSEPH M. KNAP,	WILLIAM H. BURR,	T. GUILFORD SMITH,
HORACE SEE,	JOHN THOMSON,	ROBERT B. STANTON,
WM. BARCLAY PARSONS,	ROBERT CARTWRIGHT,	AUGUSTUS MORDECAI,
F. S. CURTIS,	DESMOND FITZGERALD,	DANIEL BONTECOU,
JOHN R. FREEMAN.	HENRY D. WHITCOMB.	CHARLES WARREN HUNT.

Special Committees.

ON UNIFORM STANDARD TIME:—Sandford Fleming, Charles Paine, Theodore N. Ely, J. M. Toucey, T. Egleston.

ON ANALYSIS OF IRON AND STEEL:—Sub-Committee of the American Society of Civil Engineers (of the International Committee on Standards for the Analysis of Iron and Steel, of which Prof. J. W. Langley is Chairman)—Charles B. Dudley, William Metcalf, Thomas Rodd, A. E. Hunt.

ON UNITS OF MEASUREMENT:—George M. Bond, William M. Black, R. E. McMath, Charles B. Dudley, Alexander C. Humphreys.

The rooms of the Society are open from 9 to 17 o'clock each business day, except Saturday (when they are closed at 15 o'clock), and at other times on application to the Janitor.

HOUSE OF THE SOCIETY—127 EAST TWENTY-THIRD STREET, NEW YORK.

Vol. XXII. OCTOBER, 1896. No. 8.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS.

CONTENTS:

MINUTES OF MEETINGS.

OF THE SOCIETY.

October 7th, 1896.—The meeting was called to order at 20.15 o'clock, Vice-President B. M. Harrod in the chair; Charles Warren Hunt, Secretary, and present, also, 68 members and 14 guests.

The minutes of the meetings of September 2d and 16th, 1896, were adopted as printed in *Proceedings* for September, 1896.

A paper by W. A. Rogers, Jun. Am. Soc. C. E., entitled "The Reconstruction of Grand River Bridge," was presented by the Secretary, who read correspondence on the subject from Messrs. Onward Bates and Emile Low.

Ballots were canvassed and the following candidates declared elected:

As Members.

David Sylvanus Carll, Washington, D. C.
William Ashburner Cattell, Long Island City, N. Y.
Oscar Erlandsen, New York City.
Burton Rogers Felton, Boston, Mass.
Henry Addison Hickok, Newark, N. J.
William Hood, San Francisco, Cal.
William Byrd King, Fort Worth, Tex.
Charles David Marx, Leland Stanford University, Cal.
Henry Clay Ripley, Galveston, Tex.
Hiram Newton Savage, National City, Cal.
Hiram Abif Schofield, Chester, Pa.
Harry Taylor, Seattle, Wash.
William Andrew Thompson, La Crosse, Wis.
George William Tillson, Brooklyn, N. Y.

As Associate Members.

Arthur Lincoln Davis, St. Albans, Vt.
Alfred Peter Jacob, New York City.
Lawrence Bates Jenckes, Hammond, Ind.
David Read Lee, Syracuse, N. Y.
Willard Datus Lockwood, Rochester, N. Y.
William Roberts Michie, Greensburg, Pa.
William Augustus Moncure, Mt. Joy, Pa.
Kenneth Oake Plummer Reinholdt, Pittsburg, Pa.
Oscar Holmes Tripp, Rockland, Me.
Clarence Browning Vorce, Stamford, Conn.

The Secretary announced the election by the Board of Direction on October 6th, 1896, of the following candidates:

As Associate.

Richard Dana Upham, New York City.

As Juniors.

William Dana Bigelow, New York City.
Charles Gartensteig, New York City.
Charles Emerson Gregory, New York City.
Benjamin Franklin Latting, Brooklyn, N. Y.
Justin Oakley Reynolds, New York City.

The Secretary announced the appointment by the Board of Direction on September 1st, 1896, of the following:

Board of Censors to award the Norman Medal for 1896: William G. Curtis, Alfred P. Boller and Thomas W. Symons.

Committee to award the Rowland Prize for 1896: H. A. Carson, John F. Wallace and the Secretary.

The Secretary announced that during the months of November and December, 1896, the Library will be open for consultation every evening, except on Sundays and holidays.

The Secretary read the list of nominees * presented by the Nominating Committee for the offices to be filled at the next annual election.

The deaths of the following members were announced:

Robert Lewis Harris, elected Member May 3d, 1876; died September 29th, 1896.

Francisco de Garay, elected Fellow August 31st, 1883; died September 2d, 1896.

Vernon Hill Gridley, elected Junior February 4th, 1896; died September 17th, 1896.

Adjourned.

October 21st, 1896.—The meeting was called to order at 20.15 o'clock, President Thomas Curtis Clarke in the chair; Charles Warren Hunt, Secretary, and present, also, 121 members and 31 visitors.

A paper entitled "Suspension Bridges—A Study" was presented by Past-President George S. Morison, and discussed by Messrs. Cooper, Spilsbury, Joseph Mayer, Burr, Breithaupt, Prichard, Clarke, Collingwood and Morison. The Secretary read discussions from Messrs. G. Bouscaren and T. C. Clarke.

Adjourned.

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* See page 162.

OF THE BOARD OF DIRECTION.

(Abstract.)

October 6th, 1896.—Ten members present.

The Secretary was authorized to open the House of the Society on every night (except Sundays and holidays) during the months of November and December, 1896, and instructed to keep a record of the number of members who avail themselves of this opportunity for consulting the Library.

The list of nominees for the offices to be filled at the next annual election was received from the Nominating Committee.*

One candidate was elected as Associate and five as Juniors.

Applications were considered and other routine business transacted.

Adjourned.

ANNOUNCEMENTS.

LIST OF NOMINEES FOR THE OFFICES TO BE FILLED AT THE ANNUAL ELECTION, JANUARY 20th, 1897.

In accordance with Article VII, Section 2, of the Constitution, the Nominating Committee having presented to the Board of Direction a list of nominees for the offices to be filled at the next Annual Election, so chosen as to provide, with the officers holding over, a Vice-President and six Directors residing in District No. 1, and twelve Directors divided equally, with regard to number and residence, among the remaining districts, Nos. 2, 3, 4, 5, 6 and 7, and the Board, having examined said list, now sends it in accordance with Section 3 of the same article to every Corporate Member of the Society.

For President, to serve one year.

Benjamin Morgan Harrod, New Orleans, La.

For Vice-Presidents, to serve two years.

George H. Mendell, San Francisco, Cal., representing District No. 7.
John Findley Wallace, Chicago, Ill., representing District No. 5.

For Treasurer, to serve one year.

John Thomson, New York City, representing District No. 1.

For Directors, to serve three years.

James Owen, Newark, N. J., representing District No. 1.
Rudolph Hering, New York City, representing District No. 1.
Henry Grant Morse, Wilmington, Del., representing District No. 4.
Benjamin Lincoln Crosby, St. Louis, Mo., representing District No. 6.
Henry Stevens Haines, Atlanta, Ga., representing District No. 7.
Lorenzo M. Johnson, Eagle Pass, Tex., representing District No. 7.

* For this list, see first Announcement.

LIBRARY.

On January 2d, 1894, a petition was received by the Board of Direction from a number of members requesting that the Library be opened every Wednesday evening for the benefit of those members who could not consult it at other times. The request was granted, and the Library has been opened once every week since that date. There have never been more than five members of the Society present on any Wednesday evening, seldom as many as three, sometimes only one, and lately none. The Board, however, is desirous of making a further experiment in the matter, and has authorized the Secretary to open the Library every evening during the months of November and December, for the purpose of ascertaining whether members will avail themselves of the opportunity thus given. A record of the attendance will be kept, and the future policy in this matter will be largely governed by the result.

MEETINGS.

Wednesday, November 4th, 1896, at 20 o'clock, a regular meeting of the Society will be held, at which a paper by A. H. Sabin, Assoc. M. Am. Soc. C. E., entitled "Experiments on the Protection of Steel and Aluminum Exposed to Sea Water" will be presented. The paper was printed in *Proceedings* for September, 1896, already published.

Wednesday, November 18th, at 20 o'clock, a regular meeting will be held, at which two papers will be presented. The first, by George E. Gray, Hon. M. Am. Soc. C. E., is entitled "Notes on Early Practice in Bridge Building," and the second, by Charles Carroll Gilman, F. Am. Soc. C. E., "Experiments with a New Method of Heating and Ventilation." Both are printed in this number of *Proceedings.*

Wednesday, December 2d, 1896, at 20 o'clock, a regular meeting will be held, at which a paper by M. S. Parker, M. Am. Soc. C. E., entitled "Governing of Water Power Under Variable Loads" will be presented. It is printed in this number of *Proceedings.*

DISCUSSIONS.

Discussion on the paper by W. A. Rogers, Jun. Am. Soc. C. E., entitled "The Reconstruction of Grand River Bridge," which was presented at the meeting of October 7th, will close November 16th.

Discussion on the paper by George S. Morison, Past-President Am. Soc. C. E., entitled "Suspension Bridges—A Study," which was presented at the meeting of October 21st, will close December 1st.

Discussion on the paper by A. H. Sabin, Assoc. M. Am. Soc. C. E., entitled "Experiments on the Protection of Steel and Aluminum Exposed to Sea Water," which will be presented at the meeting of November 4th, will be closed December 15th.

Discussion on the paper by George E. Gray, Hon. M. Am. Soc. C. E., entitled "Notes on Early Practice in Bridge Building," and the paper by Charles Carroll Gilman, F. Am. Soc. C. E., entitled "Experiments with a New Method of Heating and Ventilation," which will be presented at the meeting of November 18th, will be closed January 1st, 1897.

Discussion on the paper by M. S. Parker, M. Am. Soc. C. E., entitled, "Governing of Water Power Under Variable Loads," which will be presented at the meeting of December 2d, 1896, will be closed January 15th, 1897.

MEMOIRS OF DECEASED MEMBERS.

In the number of *Proceedings* for March, 1896, the attention of members was directed to the fact that from the list of Deceased Members, dated February 10th, 1896, it appeared that no memoirs had been published of 89 persons who had been connected with the Society, and the assistance of members was asked in filling the gaps. Every effort has since been made to complete this most desirable work. It has been determined that in future, under the present system of publication, all memoirs shall be reproduced in the volumes of *Transactions*.

To date, 16 of the omissions noted above have been filled, and a number of other obituary notices are in course of preparation, but it is found in many cases that great difficulty exists in securing any one who will undertake to write sketches of the careers of some of the older members; in many instances no information of any kind is to be found, and no hint as to persons now living who possess the requisite data is obtainable.

The following is a list of such cases, and it is earnestly requested that members who have any information or notes, however brief, which will be of value in the preparation of memoirs, will forward them to the Secretary. This request, while referring particularly to the subjoined list, applies equally to recent deaths, and it is hoped that in the future such information may be sent without a special request.

The growth of the Society has made it practically impossible to carry out the very desirable method which has heretofore obtained of the appointment of a special committee to take up this work in each case. Every applicant for membership must be endorsed by at least five members before his election and his professional and personal standing must be well known. A slight and prompt effort, therefore, on the part of his friends and associates would seem to be all that is necessary to keep these records up to date. When collected in our volumes these memoirs certainly add materially to the history of the profession. As an instance of the ease with which such matters are lost

it need only be stated that Mr. James Laurie whose name appears below is No. 9 in the list of original Members of the Society and was its first President, serving as such from 1852 to 1867, and that the only note which can be found in regard to his death in its publications is a statement in Vol. 1 of *Proceedings* (1875), giving the dates of his admission and of his death, with a foot note that a memoir of him "will be published in a subsequent number of *Proceedings.*" A careful search and several inquiries have failed to develop enough information to write even a brief *résumé* of his career, although it is known that he was exceedingly active and well known for a period of at least 40 years before his death.

MEMBERS.

Name.	Date of Election.	Date of Death.
William Young Arthur	M. Dec. 4, 1867. F. Sept. 20, 1870.	Feb. 15, 1876
James Barnes	M. March 13, 1853	Feb. 12, 1869
Samuel Barrett Cushing	M. June 1, 1887	Dec. 3, 1888
Edmund French	M. Nov. 6, 1872.	May 30, 1880
John R. Gillis	M. June 2, 1869 F. Mar. 15, 1870	July 16, 1870
William Grain	M. Sept. 15, 1869	June 10, 1877
H. Grassau	M. July 6, 1853	May 16, 1870
Robert G. Hatfield	M. Dec. 4, 1867	Feb. 15, 1879
Theodore D. Judah	M. May 4, 1853	Unknown
James Laurie	M. Nov. 5, 1852	Mar. 15, 1875
J. W. P. Lewis	M. Jan. 15, 1853	Unknown
William H. Morrell	M. Nov. 5, 1852	Unknown
William W. Morris	M. Jan. 5, 1853	Unknown
Thomas S. O'Sullivan	M. Jan. 5, 1853	Nov. 1, 1855
Simeon Sheldon	M. Feb. 5, 1873	March 4, 1883
John C. Thompson	M. May 18, 1870	Jan. 17, 1880

ASSOCIATE.

Edward Wheaton	A. Mar. 3, 1880	Mar. 6, 1889

FELLOWS.

George W. Cass	F. March 30, 1871	March 21, 1888
Milton Courtwright	F. June 11, 1870	April 25, 1883
Elisha Williams Ensign	F. May 18, 1870	Oct. 1, 1877
William G. Fargo	F. May 6, 1870	Aug. 1, 1881
Henry Farnham	F. Nov. 14, 1872	Oct. 4, 1883
M. T. Seymour	F. July 21, 1870	May 30, 1885
William Williams	F. June 16, 1870	Sept. 10, 1876
J. Butler Wright	F. May 24, 1870	Oct. 31, 1877

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

		Date of Membership.
CARLL, DAVID SYLVANUS	Washington, D. C.	Oct. 7, 1896
CATTELL, WILLIAM ASHBURNER	Long Island City, N. Y.	Oct. 7, 1896
DERBY, GEORGE MCCLELLAN	Capt. Corps of Engrs., U. S. A., 1 Prytania St, New Orleans, La.	April 1, 1896
ERLANDSEN, OSCAR	136 Liberty St., New York City.	Oct. 7, 1896
FELTON, BURTON ROGERS	1120 Tremont Bldg., Boston, Mass.	Oct. 7, 1896
HICKOK, HENRY ADDISON	762 Broad St., Newark, N. J.	Oct. 7, 1896
HOOD, WILLIAM	4 Montgomery St., San Francisco, Cal.	Oct. 7, 1896
NICHOLS, EDWIN JAY	Box 234, Texarkana, Tex.	Sept. 2, 1896
POST, GEORGE BROWNE	33 East 17th St., New York City	Sept. 2, 1896
RIPLEY, HENRY CLAY	2007 Tremont St., Galveston, Tex.	Oct. 7, 1896
THOMPSON, WILLIAM ANDREW	U. S. Asst. Eng., La Crosse, Wis.	Oct. 7, 1896
TILLSON, GEORGE WILLIAM	Room 48, Municipal Dept. Bldg., Brooklyn, N. Y.	Oct. 7, 1896
VANDEVANTER, CHARLES OSCAR	Hillen Station, Baltimore, Md.	Sept. 2, 1896

ASSOCIATE MEMBERS.

DAVIS, ARTHUR LINCOLN	25 High St., St. Albans, Vt.	Oct. 7, 1896
HAWES, LOUIS EDWIN	75 State St., Boston, Mass.	Sept. 2, 1896
JOHNSON, ALBERT LINCOLN	807 Odd Fellow's Bldg., St. Louis, Mo.	Sept. 2, 1896
LEE, DAVID READ	Care N. Y. State Canals, Syracuse, N. Y.	Oct. 7, 1896
MCKINSTRY, CHARLES HEDGES	1st Lieut. Corps of Engrs. U. S. A., Newport, R. I.	Sept. 2, 1896
MONCURE, WILLIAM AUGUSTUS	Mt. Joy, Pa.	Oct. 7, 1896

ASSOCIATE.

UPHAM, RICHARD DANA	66 Broadway, New York City.	Oct. 6, 1896

JUNIORS.

GREEN, RUTGER BLEECKER	P. O. Box 3037, New York City.	May 5, 1896
LATTING, BENJAMIN FRANKLIN	424 Quincy St., Brooklyn, N.Y.	Oct. 6, 1896

CHANGES AND CORRECTIONS.

MEMBERS.

AUCHINCLOSS, WILLIAM S.......Bryn Mawr, Pa.
COLLINGWOOD, F...............Elizabeth, N. J.
COMSTOCK, CYRUS B............34 West 25th St., New York City.
COWLES, WALTER LINSLEY......Chf. Engr. Bridge & Bldg. Dept., Pottsville Iron & Steel Co., 1304 Mahantongo St., Pottsville, Pa.
DECOURCY, BOLTON WALLER....112 North J St., Tacoma, Wash.
DUANE, JAMES.................216 Edgecomb Ave., New York City.
EARL, GEORGE GOODELL.......614 Carolton Ave., New Orleans, La.
ENGLE, R. L..................Res. Eng., Main St. Bridge, Room 1, Reaves Bldg., Little Rock, Ark.
FAIRLEIGH, JAMES ANDREW......200 Pine St., Harrisburg, Pa.
FILLEY, H. H.................F. C. Mexico, Cuernavaca y Pacifico, Apartado No. 704, Mexico, Mexico.
GOODRICH, WILBUR F..........Asst. Engr. The Boston Ter. Co., Room 57, 180 Summer St., Boston, Mass.
HARRIS, WILLIAM POND.........Plant System of Railways, Gainesville, Fla.
HERMANN, E. A................505 North Spring Ave., St. Louis, Mo.
HUGHES, WILLIAM M...........1512 Great Northern Bldg., Chicago, Ill.
JENKINS, WILLIAM DUNBAR..... Chf. Engr. Aransas Pass Harbor Co., Tarpon, Tex., *via* Rockport.
LINVILLE, JACOB HAYS.........P. O. Box 415, Phila., Pa.
LOW, EMILE...................1101 Morgan Bldg., Buffalo, N. Y.
MOSMAN, ALONZO TYLER.......513 B St., N. E., Washington, D. C.
TOWNSEND, CURTIS McD........136 Island St., Grand Rapids, Mich.
WHITFORD, O. F...............485 Pearl St., Buffalo, N. Y.
WILLARD, JAMES EAGER.......Little Rock, Ark.
WILLIAMSON, FRANCIS STUART....1 Broadway, New York City.
WILLIAMSON, WILLIAM GARNETT.U. S. Asst. Engr., 723 Monroe St., Montgomery, Ala.

ASSOCIATE MEMBERS.

CRABBS, CLARENCE LINCOLN.....6501 Lafayette Ave., Chicago, Ill.
FELTON, BURTON ROGERS.......1120 Tremont Bldg., Boston, Mass.
GRAY, EDWARD, Jr............City Hall, Richmond, Va.
HAZLETT, ROBERT.............City Bank Bldg., Wheeling, W. Va.
HEMMING, D. W...............153 West 98th St., New York City.
KYLE, GEORGE ALLAN..........Const. Engr. Simmer & Jack Gold Mining Co., Ltd., Germiston P. O., South African Republic.
LINDENTHAL, DOMINIK.........1047 East 175th St., New York City.
MITCHELL, EDWIN.............5 East Lexington St., Baltimore, Md.
McKEAN, REGINALD............Bond Hill, Ohio.
ROBINSON, HOLTON DUNCAN......357 West 121st St., New York City.
STACKPOOLE, STEPHEN WESTROPP.Apartado 423, Mexico, Mexico.
STEVENS, ALEXANDER..........99 Cedar St., New York City.
TREADWELL, LEE..............Pencoyd, Pa.

ASSOCIATE.

JOHNSTON, JOHN PARRY.........526 North Ave., Station D, Pittsburg, Pa.

JUNIORS.

ADEY, WILLIAM H............. Swarthmore, Pa.
BALLOU, GEORGE LANGDON.......Care of Buffalo Engineering Co., Erie Co. Bank Bldg., Buffalo, N. Y.
BARNEY, PERCY CANFIELD.......421 Park Place, Brooklyn, N. Y.
BELL, GILBERT JAMES..........Ft. Madison, Iowa.
CRAIG, WASHINGTON RIGHTER...Supervisor N. & W. R. R. P. O. Box 257, Winston, N. C.
HARRIS, VAN ALEN.............111 Main St., Marlboro', Mass.
MAGOR, HENRY BASIL...........105 So. Oxford St., Brooklyn, N. Y.
PARKER, CHARLES F............27 William St., New York City.
SMYTH, ARTHUR MOULT.........347 West 123d St., New York City.
TAPPAN, ROGER................Russell Cottages, Kearsarge, N. H.

DEATHS.

GRANT, WILLIAM HARRISON.....Elected Member July 2d, 1873; died October 10th, 1896.
GARAY, FRANCISCO DE...........Elected Fellow August 31st, 1883; died September 2d, 1896.
GRIDLEY, VERNON HILL.........Elected Junior February 4th, 1896; died September 17th, 1896.
HARRIS, ROBERT LEWIS.........Elected Member May 3d, 1876; died September 29th, 1896.
NOYES, ALBERT FRANKLIN.......Elected Member December 3d, 1884; died October 12th, 1896.
NEILSON, ROBERT..............Elected Member February 17th, 1869; died October 12th, 1896.

ADDITIONS TO

LIBRARY AND MUSEUM.

From American Institute of Mining Engineers:
- Additions to the Power-Plant of the Standard Consolidated Mining Company.
- A Modern Silver-Lead Smelting Plant.
- Biographical Notice of Charles A. Stetefeldt.
- Determination of Phosphorus in Steel.
- Electric Mining in the Rocky Mountain Region.
- Further Notes on the Alabama and Georgia Gold Fields.
- Gold in the Guyanas.
- Laboratory Tests in Connection with the Extraction of Gold from Ores by the Cyanide Process.
- Note on Copper in Iron and Steel.
- Note on a Shaft-Fire and its Lesson.
- Silver Losses in Cupellation.
- Sketch of a Portion of the Gunnison Gold Belt.
- The Accumulation of Amalgam on Copper Plates.
- The Actual Accuracy of Chemical Analysis.
- The Bertrand-Thiel Open-Hearth Process.
- The Concentration of Ores in the Butte District, Montana.
- The Cyanide Process in the United States.
- The Magnetic Separation of Non-Magnetic Material.
- The Microstructure of Steel and the Current Theories of Hardening.
- The Occurrence and Behavior of Tellurium in Gold Ores.
- The Smuggler-Union Mines, Telluride, Colorado.
- List of Officers, Members, Rules, etc.

From Boston Public Library, Boston, Mass.:
Monthly Bulletin of Books added October, 1896.

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Transactions, Vol. I, No. 7. Flow of Water in Pipes.

From C. O. Gleim, Hamburg, Germany:
Neuere Stadt und Vorortbahnen in London, Liverpool und Glasgow mit Nutzanwendung für die Hamburger Vorortbahn-Frage.

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Seventh Annual Report of the Syracuse Water Board for the year ending June 30th, 1896.

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Untersuchungen über den Seitendruck der Erde auf Fundamentkörper.

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Minutes of Proceedings, Vol. CXXV.
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The Surveyor, Vol. VIII, 1895.

From Master Car Builders' Association:
Report of the Proceedings of the Thirtieth Annual Convention, June 17th, 18th and 19th, 1896.

From William Metcalf, Pittsburg, Pa.:
Steel: A Manual for Steel Users.

From N. Y. Central and Hudson River Railroad Co., New York, N. Y.:
Twenty-seventh Annual Report for the year ending June 30th, 1896.

From C. Y. O'Connor, Perth, West Australia:
Report on Proposed Water Supply (by pumping) from Reservoirs in the Greenmount Ranges.

From J. A. Ockerson, St. Louis, Mo.:
Detail Charts of the Lower Mississippi River from the Mouth of the Ohio River to the Head of the Passes, Louisiana.

From Ohio Society of Surveyors and Civil Engineers, Columbus, Ohio:
Seventeenth Annual Report, February, 1896.

From Patent Office, London, Eng.:
Abridgment of Specifications for Patents for Inventions, 1884-88.
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From George W. Rafter, Rochester, N. Y.:
On Lake Erie as a Water Supply for the Towns on its Borders.

From Royal Society of Canada, Ottawa, Can.:
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From John C. Trautwine, Jr., Philadelphia, Pa.:
Experiments upon the Contraction of the Liquid Vein issuing from an Orifice, and upon the Distribution of the Velocities within it. (Translated from the French of H. Bazin.)

From U. S. Commissioner of Education:
Report of the Commissioner of Education for the year 1893-94. Vols. 1 and 2.

From U. S. Geological Survey:
Five Maps of the Geological Survey.

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Official Register of the Officers and Cadets of the U. S. Military Academy, West Point, N. Y., June, 1896.

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Astronomical, Magnetic and Meteorological Observations made during the year 1890.
Astronomical Papers. Vol. V, Part 5. The Mass of Jupiter and the Orbit of Polyhymnia.
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From U. S. Patent Office:
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From U. S. War Department, Chief of Engineers:
Forty Specifications for the Improvement of Certain Rivers and Harbors.

From U. S. War Department, Chief of Ordnance:
Report of Tests on the Strength of Structural Material made at the Watertown Arsenal, Mass., for the years ending June 30th, 1890, 1891 and 1892.
Notes on the Construction of Ordnance, No. 69.

BOOK NOTICES.

THE CAMBRIDGE OF EIGHTEEN HUNDRED AND NINETY-SIX.

A Picture of the City and its Industries, Fifty Years after its Incorporation, done by divers Hands and edited by Arthur Gilman, A. M., under the direction of a Committee of the City Government and Citizens. 6½ x 9¾ ins., cloth. Cambridge, Riverside Press, 1896, pp. 421.

This book is the result of a meeting of the Citizens' Trade Association of Cambridge, held in December, 1895. At this meeting a committee was appointed to act, in conjunction with a committee of citizens, in the collection of statistics, showing the city's advantages as a place of residence and for business opportunities, and of all information the publication of which would tend to advance its interests.

Monographs by different authors upon all the principal historic, literary, social, religious and business features of the city are given, with much information which must be of interest and value to all its citizens.

Separate chapters give the origin and history of Harvard University, Radcliffe College, the theological, public and private schools and of the churches, hospitals and beneficial societies.

The book is illustrated by over fifty plates of buildings, and places of interest in the city.

A TREATISE ON SURVEYING, COMPRISING THE THEORY AND THE PRACTICE.

By William Gillespie, LL. D. Revised and enlarged by Cady Staley, Ph.D., President of Case School of Applied Science. Part I. Land Surveying and Direct Leveling. 6½ x 9 ins. cloth, pp. 424 + 127. New York, D. Appleton & Co., 1896.

Prof. Gillespie's "Land Surveying" and "Leveling and High Surveying," issued in 1851 and 1870, respectively, and united in one volume by Professor Staley, in 1887, have been so long used as text books in preparatory and technical schools, that their value is well known.

The present edition of the united books has been considerably enlarged, and the reviser has thought it necessary to divide it into two volumes, to meet the requirements of the two classes of schools for which it is intended

Part I, on plane surveying, includes land surveying and direct leveling, and Part II will be given to trigonometric and barometric leveling, topography, geodesy, field astronomy, hydrographical, city and mining surveying and other special subjects.

1896. OCTOBER. No. 8.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CONTENTS:

NOTES ON EARLY PRACTICE IN BRIDGE BUILDING.

By GEORGE E. GRAY, Hon. M. Am. Soc. C. E.

TO BE PRESENTED NOVEMBER 18TH, 1896.

In reviewing the paper entitled "What Is the Life of an Iron Railroad Bridge?"* by J. E. Greiner, M. Am. Soc. C. E., and the discussion on it, the author was particularly interested in the remarks of T. C. Clarke, M. Am. Soc. C. E., and Walter Katté, M. Am. Soc. C. E., re-

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* See *Transactions*, Vol. xxxiv, p. 294.

ferring to certain bridges on the New York Central and Hudson River Railroad. The conclusions arrived at by these members on this question are, in the author's opinion, generally correct. These conclusions are that the practice of placing the diagonals closer than is now customary led to diffusing the strains over a large number of points rather than concentrating them on a few, which is one of the reasons the bridges stood so well. Mr. Katté was of the opinion that solidly riveted lattice girders, up to spans not exceeding 200 ft., give unquestionably the best service for such constant and heavy traffic as that on the New York Central system.

It was contemplated in the original design for the bridges referred to, to connect all of the parts by riveting, thus diffusing the strains throughout the whole structure. The advantage of this system was soon clearly illustrated at a bridge of this type just erected over the Erie Canal near Newark, N. Y. A fast express passenger train was bound westward, and as it approached within a few feet of this bridge the axle of the forward driving wheels, outside connections, broke off close to the right-hand wheel. This left the wheel free, and, being propelled with great velocity forward, it left the rail, striking in its course the second outside right-hand post, from the easterly end of the bridge, cutting the post off entirely, together with several tension bars. In addition, the third and fourth posts were nearly severed and several tension bars more or less cut away, but the rigid connections of the structure carried the train over safely, and, in fact, there was no delay in passing all other trains while repairing the damage. It is gratifying to the author to hear, after so many years, such testimony in recognition of the labor and efforts of himself and his able assistant, the late Col. Howard Carroll.

The bridges referred to were designed and constructed before 1864 and 1865. It may be of some interest, historically, to engineers and others to know, what the author believes to be true, that the New York Central Railroad Company was the first to build an all wrought-iron bridge of any considerable span for railroad use in the United States. Several bridges, cast and wrought iron combined, had been constructed on the Whipple and other designs, but the failure of one of them on the New York and Erie Railroad, through the ignorance of track men, caused railroad officials to look with distrust on any iron bridge.

The process that led up to the adoption of iron for bridges in the United States was slow. The author, as chief engineer of the New York Central Railroad Company, was directed to examine carefully into the subject of iron bridges and report to its Board of Directors. The high price of iron and the general lack of knowledge of its use for such purposes made it difficult to get a reasonable consideration of the subject by those high in authority. In working out the plans and strain sheets a serious question arose as to how much a given section would bear under compression without bending. Upon this question the highest authority then accessible was silent, and the author had to work it out by erecting the proper testing machinery for that purpose at the New York Central shops at Albany, N. Y. Finally, when authority was obtained and plans and estimates prepared, the directors and officials were skeptical. To convince the skeptics, a single-track bridge of 30-ft. span, proportioned to 1 ton per lineal foot, was built at Schenectady, solely for tests, and to be so used until broken.

A 28 to 30-ton locomotive, the heaviest then on the road, was run over this bridge at high speed without any defects appearing. Thereafter the bridge was loaded by dead weight, evenly distributed, to over 4 tons per lineal foot, when the bridge failed from a defective tension bar. Up to this period the rule had been to proportion all bridges to a load of 1 ton per lineal foot. Soon after the rule was changed to a proportion of 2 tons per lineal foot, this being in view of the demands of increasing traffic and the constant tendency to enlarge the capacity of locomotives and rolling stock generally.

The question of corrosion entered seriously into the author's calculations originally. Skeptics made telling arguments as to the unreliability of iron on that account, therefore extra precautions were taken to protect each part of the iron promptly on delivery. Long after, so anxious had the author become on this subject, and fearing neglect to keep the bridges well protected from so insidious an enemy, he wrote from California to his direct successor, Mr. Charles Hilton, and again to Mr. Charles H. Fisher, his successor, both among his former assistants on that road, calling their attention to this subject and urging watchfulness and care. Mr. Fisher replied, that, mindful of the danger, he had called the attention of his superiors to this subject; that they had expressed no concern, were apparently indifferent, and,

furthermore, said that the danger, if any, was so remote there was no need of apprehension. An inspection of the bridges referred to should bear witness of any damage by corrosion after a period of 35 years or more.

Can the engineer be held responsible when his principals are so indifferent to the inroads of such an enemy as corrosion, in fact, the only enemy of any account the engineer has to fear?

The author is wedded to rigid connections and would not limit spans to 200 ft., as proposed by Mr. Katté, except on economical grounds, such as rapid erection, or the continuous running of trains during erection. Riveted connections largely avoid vibration, the great demoralizer of all iron and steel bridges. It is his firm belief that had a bridge with pin connections been in the place of the present bridge at Newark, erected over 32 years ago, the whole train, with its precious load of passengers, would have been plunged into the Erie Canal below.

To the engineer of this date, with all the accumulated knowledge and experience of the past 35 years, with perfection of machinery and material and the developed science of bridge building, the foregoing remarks may seem not worth commenting upon; but he should feel thankful that those who preceded him had made his road easier and that he is not hampered, as they were, by lack of experience, a very meager bridge literature and prejudiced opposition.

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EXPERIMENTS WITH A NEW METHOD OF HEATING AND VENTILATION.

By CHARLES CARROLL GILMAN, F. Am. Soc. C. E.

TO BE PRESENTED NOVEMBER 18TH, 1896.

The principle of the method of heating and ventilation discussed in this paper is the utilization of the fact that air rarefied by heating will cause a circulation in the rooms of a building. This principle is applied practically by cooling the air near the ceiling of a room, by heating the air near the floor, or by both means. It has been the belief of the author for some time past that the mechanical condition for such a system of heating might be furnished by the use of "earthen-ware-house" construction in the floors and ceilings, and to test the validity of this belief he carried out the two sets of experiments described hereafter.

The first set of experiments was carried out in the kitchen of the author's village homestead, which was then vacated for repairs. It has a water-backed cook stove piped for domestic uses, to waste in the bathroom on the floor above, and is supplied by a tank in the attic.

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The stove was taken out and set in the cellar below, and the flooring and ceiling coverings were ripped out. Porous brickstuff planks, 1¼ ins. thick, were then fitted and spiked on the exposed faces of the floor joists, in order to furnish an air-tight and fire-proof foundation. This floor measured 12 x 16 ft., and served as a support for a heating coil composed of lengths of 1¼-in. iron pipe laid 12 ins. apart, and suitably connected with the water back of the stove on the floor below. This coil was tested for leakage and provided with a petcock to enable air to escape, and the whole floor was then covered with a 4-in. layer of concrete made of equal volumes of native hydraulic lime, sand and small gravel, as shown in Fig. 1.

For the purposes of the experiment a temporary ventilating ceiling was made by sheathing the under surfaces of the rafters with ¾-in. matched pine boards. This ceiling was perforated with 144 auger holes from 4 ins. to 6 ins. apart. One-third of these were 1 in. in diameter and the remainder ⅝ in. Five of the 1-in. holes were provided with tin tubes opening in the floor of the bathroom, and the remainder opened into the wall void, 10 ins. in depth, having direct communication with the outside air.

About three months later, the floor had hardened and the experiment was begun. A platform was put up near the ceiling, the auger holes were corked from below, and blankets were hung over the inside of the doors as an additional precaution against the entrance of the air. A thermometer was affixed to a partition wall at the floor level, another at an elevation of 6 ft. and a third at the ceiling. A fire was then started in the stove and maintained for three hours, when the kitchen was entered. Each of the three thermometers indicated a temperature of 72°, the water in the floor coil was at 135° and the temperature outside the house was 40 degrees.

To rid the room of humidity, the corks were drawn, which was followed at once by a drop of 4° in the reading of the middle thermometer, the others remaining at their former reading. It was found that all the larger orifices, except the five opening into the bathroom, were discharging air downward, while no movement was discernible at the mouths of the smaller ones. The five tubes leading to the bathroom were discharging air upward under a pronounced pressure, although not of a volume equal to that dropped into the room through 43 holes of the same size. The only explanation of this state

of affairs is that the outside air at 40° entering through 43 1-in. holes was pushing up, because of its greater weight, the rarefied air at 72° through 96 $\frac{5}{8}$-in. holes and the five 1-in. holes leading to the bathroom.

Subsequently the floor of the adjoining room, measuring 16 x 18 ft., was provided with a similar coil, and the experiment repeated with the same results, except that six hours instead of three were required to bring the water to the same temperature.

Fig. 1

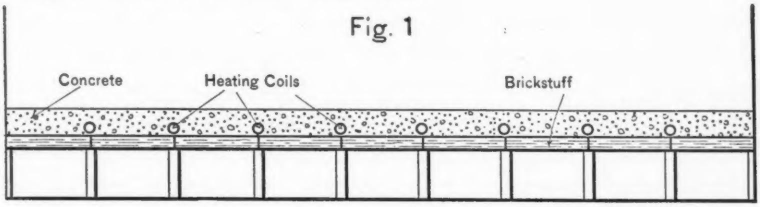
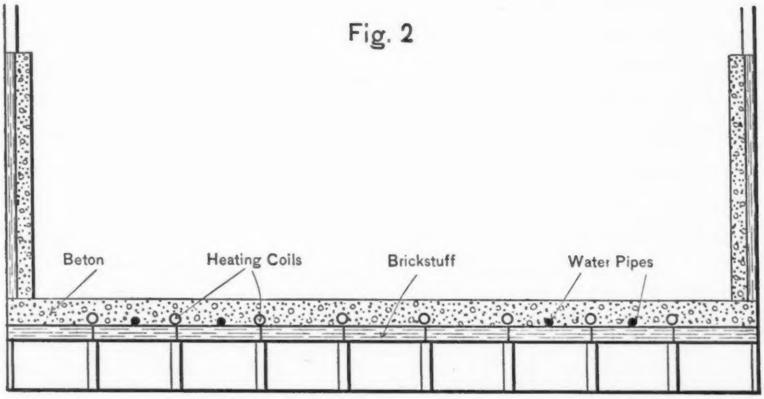


Fig. 2



These experiments show that under the given conditions there is an exchange of hot and cold air at the ceiling, which prevents draughts, and it is practicable to warm a small cottage with kitchen, living room and two bedrooms, having about 500 sq. ft. of floor area, by means of water from the stove.

The second series of experiments was carried out in a small greenhouse annexed to a steam-heated dwelling. The greenhouse was a frame structure measuring 10 x 20 ft. in the clear, and 14 ft. high above the floor. The walls were sheathed to a height of 4½ ft. with brick-

stuff, the remaining distance and the roof being of glass, single sashed but double glazed. The floor was prepared somewhat like that of the kitchen already described, and contained in addition to the heating coil several water pipes, as shown in Fig. 2. The floor was made by soaking brickstuff planks in water before laying them, and using as a covering a mixture of one part of Portland cement to four parts of clean, sharp sand, screened through a No. 6 sieve. The concrete previously employed was not used on account of its deficiency as regards the conduction of heat. The greenhouse has four ventilating transoms beneath the eaves, a small door leading to an open porch and four large folding doors, which, when thrown back, make the greenhouse and adjoining music room practically one large room. The floor coils were supplied with steam from the boiler in the house. The entire cost of the new outfit complete was about \$2 per square foot of floor area.

Sixty days after the completion of the work steam at 7 lbs. pressure was turned on. The outside air was at 29° at the time and the air in the annex at about 65 degrees. It was found by means of smoke tests that the currents of air were rising from the floor to within several inches of the roof, where they spread out horizontally to the walls and sank to the floor. The only ventilation was through a small crevice between the roof and its supporting wall plate, and under the door leading to the porch. The transoms were not used until spring. The mean temperature maintained was 75° during the day and 60° at night, although several times when the outside air was 18° to 22° below zero, the temperature in the greenhouse sank to 52° in the early morning. The furnace fire was banked from 10 P. M. to 6 A. M., the greenhouse being warmed during the interval by the heat stored in the floor. Roses, chrysanthemums, carnations and other plants bloomed freely in their respective seasons, and bulbs, cuttings and seeds were started successfully in the spring.

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PAPERS.

GOVERNING OF WATER POWER UNDER VARIABLE LOADS.

By M. S. PARKER, M. Am. Soc. C. E.

TO BE PRESENTED DECEMBER 2D, 1896.

The government of water power under variable loads has always been considered a difficult problem under the most favorable conditions. Many operators of water-power plants where changes in load are great and sudden have found their government so uncertain and near the danger line that it was believed a few years ago that small electric street railway plants could not be successfully operated by water power. With large plants the change in load represents but a small percentage of the whole power in use, so that the variation in load is not so extreme as to cause serious difficulty in the government of the power. It is the extreme and sudden changes that cause trouble.

The modern ball governor, as used to regulate water wheels, is satisfactory in its operation where the power used is fairly constant, but becomes entirely inadequate for the government of water power where

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the changes of load are sudden and extreme. The author had this problem of the government of water power brought to his attention a few years ago and found little published data to assist him in solving it. The solution became a matter of experiment. The result of these experiments and the conclusions drawn from the investigation may be of some interest to the engineering profession. The paper is presented in the hope that engineers having experience in governing water power under variable loads will discuss the problem and throw as much light as possible on this comparatively unexplored field of hydraulic practice.

The power to be governed consisted of a pair of 22½-in. Victor turbine wheels working under 40 ft. head. These wheels generated about 400 H.-P. on the wheel shaft, which is used in operating 6 miles of electric street railway, having a twenty-minute service. On this line are employed from four to ten cars daily, equipped with two 15 H.-P. single motors. The extremes of variable load are of daily occurrence. There are moments when with four or more cars in service the load is suddenly removed by the stopping of all cars at once, making a sudden change from a load of 120 H.-P. or more to no load on the generators.

This was the cause of frequent annoyance and expense due to the burning out of armatures, as the ball governor of the water wheels does not act quickly enough to prevent racing of the wheels at times. A large fly-wheel roped with five 2-in. diameter ropes from the wheel shaft failed to hold the wheels always in check. When the wheel governor, assisted by the balance wheel, succeeded in checking the speed, as frequently occurred, the recovery of the necessary power to operate the entire load was necessarily slow in action, causing delay in the starting of the cars. These results are too well known to those who have had any experience in trying to operate a water power under extreme variable loads to need further notice. The water to operate the wheels mentioned is conducted from the head works at the dam to the wheels through a penstock 9 ft. in diameter and 400 ft. long. The absence of a vent or standpipe on the penstock made the problem of government of the power still more difficult of solution. It has been the practice among hydraulic engineers, so far as the author is aware, to disregard length in penstocks in designing water-power plants. From the author's observation and experience it is shown that the

shorter the column of water in the penstock, the easier it can be regulated or governed in flow at the wheel. In other words, in reducing the time of getting power from the water to a minimum where long penstocks are indispensable, it will add greatly to the facility of governing the water if a standpipe is placed on the penstock near the wheels to be governed, of a diameter equal, or nearly so, to that of the penstock. The vent pipes as generally used on such penstocks are entirely too small to be of any material service in governing the water power developed. It is readily understood that when the velocity of flow of the water in a long penstock is checked, time is required for

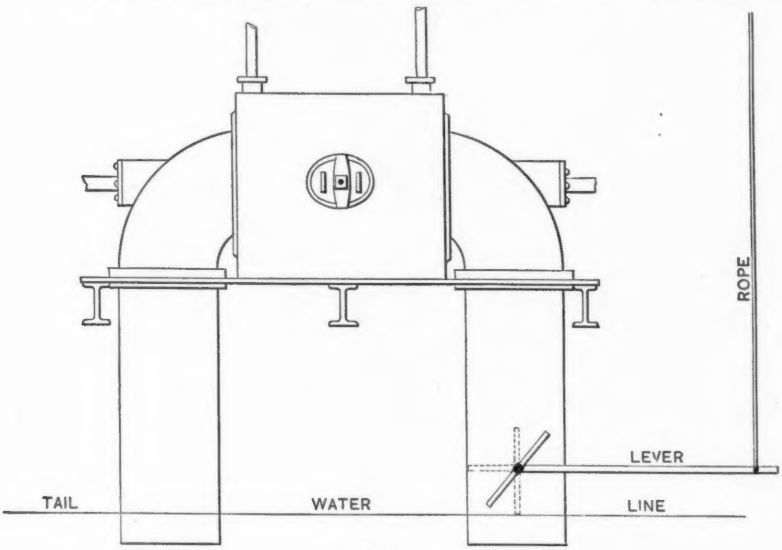

FIG. 1.

the same velocity to be again acquired. The standpipe suggested for such cases acts as a governor and brings the actual head of water into effect in the minimum period of time. It acts as a reserve force to allow the water in the penstock to regain the required velocity.

The power company had under consideration several electrical devices for relieving the machines of surplus current, but these were abandoned, either as being too expensive to be considered or as being insufficient in operation. A patented electric governor was obtained and has now been in operation for about two years and has proved successful beyond all expectations.

The governor was placed in position under a guarantee from the inventor to accomplish certain results or receive no compensation for the governor. He failed to accomplish the promised conditions, but the result was so highly satisfactory and such an improvement over anything before tried that the company gladly paid for the governor.

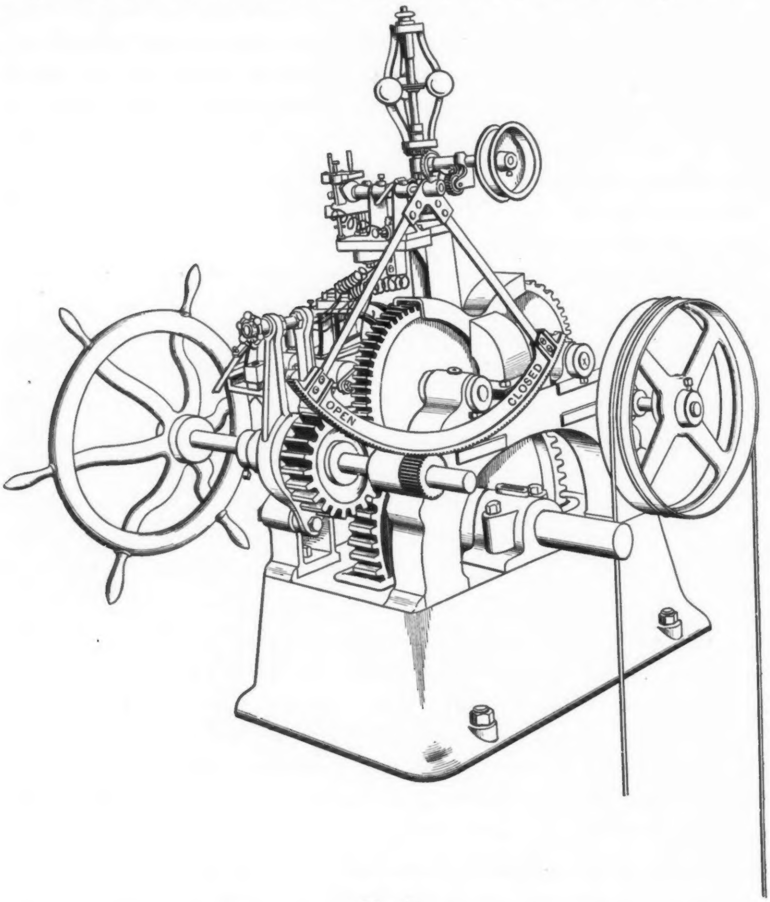

FIG. 2.

Some minor improvements since made have brought it up to the promised efficiency.

The electric governor consists of a gate regulator, a high speed engine regulator and a common telegraph or gravity battery, with its circuit. The regulator is powerful enough to control the wheel

gates, and receives its power directly from the wheels. It is also so sensitive that the battery current will cause it to move the gates as desired. The engine governor is simply used as an indicator of speed, and as the indicator rises or falls it makes an electric contact, telegraphing the regulator which way to move the gate. There is no limit to the distance that may be between engine governor and gate regulator. Fig. 1 is a cut of the governing gate in use. This gate is placed in the draft tube, and is known as a butterfly or damper gate. To the gate axis, extending through the draft tube, is attached a lever, worked by means of a wire rope attached to a pulley on the

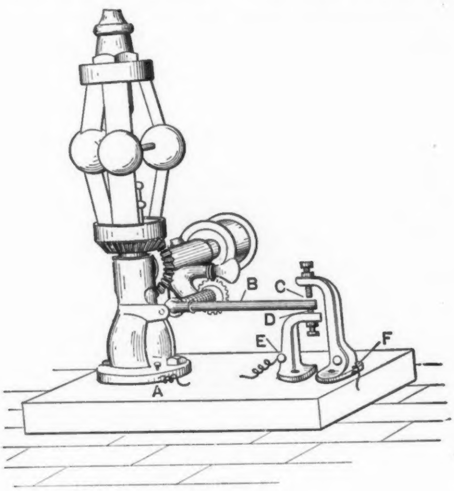

FIG. 3.

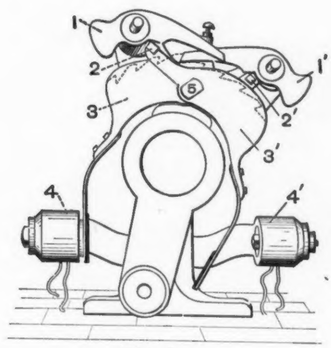

FIG. 4.

regulator, the gate being opened or closed as the speed of the regulator increases or diminishes, the register gate of the turbines being left wide open constantly while the wheels are in operation. Fig. 2 is a general cut of the governor. The wire rope passes several times around the pulley shown on the right of the cut, one end of the rope being attached to the lever of the gate in the draft tube, and the other end to a counter-balance weight. The end to which the counter-weight is attached was formerly made fast to the pulley. The substituting of a counter-weight for this arrangement is advisable, as it is a help to quick action, and relieves the machines of an unnecessary load in closing the gate.

Figs. 3 and 4 show the electrical connections of the speed governor and regulator pawls. The speed governor is belted to the shaft to be regulated, and a rise or fall in the speed of the shaft causes a corresponding rise or fall in the little lever *B*. The lever *B* is a portion of the battery circuit, and in falling makes or completes the circuit at the contact *D*, which is connected by wire to magnet 4. Magnet 4 becomes energized and attracts armature 3, lowering lug 2, which action permits gravity to drop pawl 1 into the ratchet shown in dotted lines. The motion of the ratchet wheel opens the gates. This operation is instantaneous, and gives to gravity the advantage of time that is lost in the heavy slow-acting balls which must necessarily be used in mechanical water-wheel governors. A reverse of this process will close the gate.

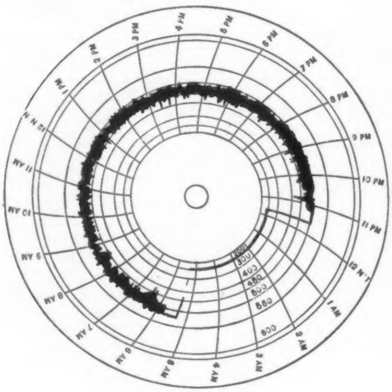

Fig. 5.

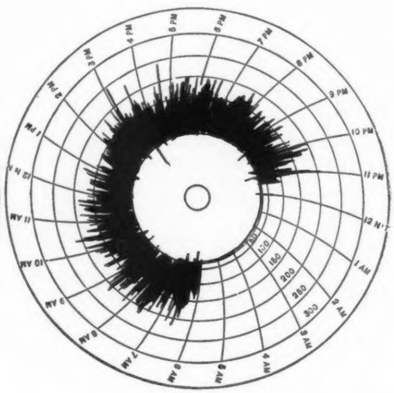

Fig. 6.

"Gravity is the force from which we derive energy in water power. The energizing effect is constant as far as pressure is concerned. If more power is required from a water wheel at any time it must necessarily come from one or both of the only two sources available under the existing conditions, namely, the existing pressure maintained during a longer time, or a greater area of pressure during the same time. Since it is impossible to maintain an even speed for fluctuating loads by the former source, we must resort to the latter. And since it requires time for gravity to energize or give motion to the increased quantity of water required for an increase of load, it is evident that most valuable time can be saved by opening the gates at the earliest possible indication of decrease of speed."

The foregoing in the language of the inventor correctly asserts the principle upon which this governor is constructed. He accomplishes

this result by an extremely sensitive governor, the sole duty of which is to indicate variations of speed. The battery power serves simply to trip the pawls which throw the gate mechanism into action. Fig. 5 is an average voltage card for a day's run on the electric street railway. It is taken at random from the daily cards taken at the power station. Fig. 6 is the recorded amperage for same day. These records do not fall much below the average records of the best governed engine work. This governor, as will be seen from the description, is not an expensive piece of mechanism. Its construction is simple. The expense of maintenance for the time it has been in service under the author's observation consists of the occasional renewal of the wire rope. While the author is not prepared to say that this is the best device on the market for the government of water power under variable loads, he can say that it is the best and least expensive device that has come to his notice, and that it has solved the problem of the government of water power under extreme variable loads in the instance herein cited. In his opinion there is no reason existing why water power cannot be successfully employed, where variable loads are the rule, by the use of electric governors. The conditions should be made as favorable as possible in original construction, and the electric principle applied to governing the gates will give satisfactory results in steady power.

MEMOIRS OF DECEASED MEMBERS.

NOTE.—Memoirs will hereafter be reproduced in the Volumes of *Transactions*. Any information which will amplify the records as here printed, or correct any errors, should be forwarded to the Secretary prior to the final publication.

SQUIRE WHIPPLE, Hon. M. Am. Soc. C. E.*

DIED MARCH 15TH, 1888.

Squire Whipple, the son of James and Electa Johnson Whipple, was born in Hardwick, Mass., on September 16th, 1804. His father was a farmer and later the owner of a small cotton mill, and the son spent the earlier period of his life in work connected with the farm and the mill. For about six months in each year he attended the district schools of Hardwick until he was thirteen years of age, at which period, or in 1817, his father removed to Otsego County, N. Y, and the son again assisted him in farming. After teaching school for a time Squire Whipple attended the academical schools of his neighborhood, and in 1829 he entered the senior class of Union College, at Schenectady, N. Y., and was graduated one year later, with the degree of A. B., from that institution.

His early connection with the machine shops of his father's mill at Hardwick had assisted in developing a natural inclination towards mechanical pursuits and had to a certain extent guided him in his studies. The construction of the Erie Canal and other public works nearby induced him later to enter the new and then very vaguely defined field of civil engineering, and, upon leaving Union College in 1830, he sought occupation of this character. He first found work as a rodman, and later as leveler, upon the Baltimore and Ohio Railroad; but his service with that company seems to have been short, and he was chiefly occupied for some years under Holmes Hutchinson, late of Utica, N. Y., in fixing the boundaries of land necessary for the construction and maintenance of parts of the Erie Canal, and in surveys and estimates for the enlargement of this waterway. In 1836–37, he was for a short time resident engineer on the Eastern Division of the New York and Erie Railway, under the late Edwin F. Johnston, as chief engineer; but work was soon suspended upon this enterprise and he was out of employment. With the exception of five or six surveys and reports upon projected railways and canals, submitted between 1837 and 1850, the list here mentioned constitutes about all of the experience of Mr. Whipple in general field practice.

In the intervals of enforced leisure Mr. Whipple turned his attention to the manufacture of engineering field instruments; and about

* Memoir prepared by D. McN. Stauffer, M. Am. Soc. C. E.

25 leveling instruments and several fully equipped transits were made by him at this time. In 1840 he brought out his first invention of any note in the form of a scale for weighing canal boats of from 200 to 300 tons. He made a model and later built the first enlarged weighing lock scale ever constructed upon the Erie Canal. This scale worked satisfactorily and served as a model for others built by Mr. Whipple and those following his designs.

Mr. Whipple's first patent for an iron truss bridge was taken out on April 24th, 1841, and, while this was not for a pin-connected truss, it possessed some of the features of the present practice in bridge design. As well as can be learned from the meager drawings and specifications then submitted for United States patents, this bridge may be described as follows : The top chord was a cast-iron arch, of channel section, widening in plan from the center towards the ends, built in sections "from 10 to 20 ft. long," and with the several parts united at the panel points by a kind of socket joint with a pin passing through both parts of the arch. The bottom chord was made of round rods, apparently connected at the foot of each vertical to a channel-shaped casting, which served as a transverse floor-beam, and secured by nuts inside this channel. The verticals were round iron rods, somewhat vaguely described as acting "as both ties and posts," and the diagonal system in each panel was made of rods, or "braces of cast iron," placed in pairs. According to the drawing, these diagonal rods were secured by nuts to the top chord and to the transverse floor-beam before described. Mr. Whipple built a number of these bridges, with spans ranging from 70 to 100 ft., over the Erie Canal, and of the fifty iron bridges erected in the United States prior to 1850 these structures constituted the large majority.

About 1852, Mr. Whipple designed and built several short and unimportant iron railway bridges upon the New York and Erie Railway; but though they successfully withstood severe tests and were in use for some months, they were removed owing to a panic caused by the failure of another iron bridge on the same line, of different design and proportions. But in 1852–53 he constructed a Whipple trapezoidal iron railway bridge, of 146-ft. clear span, upon the Rensselaer and Saratoga Railroad, near West Troy, N. Y. This is claimed to be the first iron bridge built with inclined end-posts, and the type was afterwards well known as the Whipple truss. It successfully withstood the gradual increase in the weight of rolling stock until 1882, when it was taken down and replaced by a double-track structure of modern design.

From an illustrated description of this bridge, written by Squire Whipple himself and published in *Engineering News* of April 7th, 1883, the following brief abstract is made : This bridge had parallel top and bottom chords, inclined end posts and a double intersection diagonal system, with the compression members made of cast-iron. The bot-

tom chord was constructed of iron links of various diameters connecting over cast-iron trunnions forming a part of the cast post-shoe. The top chord was constructed of hollow cast-iron cylinders abutting on a round pin above the post; and this pin rested upon a semicircular groove in an extension of the post and also secured the tops of the diagonal members, which were provided with an eye for this purpose. The lower ends of the diagonals passed through the cast post-shoe and were secured there and adjusted by nuts. The posts were tapering hollow castings, in four sections, bolted together by flanged joints and trussed at the center to guard against buckling and to compensate for an opening left in the center of the post for the passage of the diagonals. While this bridge might be said to be pin-connected above, the bottom connection was made by the cast-iron trunnions before mentioned, which were from 7 to 9 ins. long and 3 ins. in vertical thickness, and rounded off at both ends to fit the links. This bridge was built upon a skew, with an angle of 44°, and it was originally submitted to a test of 150 tons of railway iron, distributed, and the passage of a 40-ton locomotive drawing a train of loaded freight cars covering the bridge. It was proportioned for a rolling load of 1 ton per foot only, and was probably the lightest iron railway bridge of like span ever constructed, for the metal in it is said to have weighed only 75 000 lbs., 43 000 lbs. of this being cast iron.

Early in 1847 Mr. Whipple published a brief but practical treatise upon bridge designing; and in 1869 he issued a continuation of this work, for which he set the type, made the woodcuts and printed off the sheets on a small hand-press at his own home. This original treatise is noticeable for the general soundness of his reasoning, and as being one of the very earliest attempts to handle the problems of bridge design and proportions upon well-digested scientific principles.

The full title of the book, as printed by H. H. Curtiss, of Utica, N. Y., was: "A Work upon Bridge Building, Consisting of Two Essays, the One Elementary and General, the Other giving Original Plans and Practical Details for Iron and Wooden Bridges." In this treatise Mr. Whipple pointed out and illustrated the fundamental law of framed structures and gave rules and formulas for determining the exact amount of stress brought upon the several members of a truss or bridge. He also discussed the relative economy of various arrangements of members, and, in fact, forecast much that is now actual practice. Mr. Whipple claimed no originality for the use of diagonal members between parallel chords; but he appears to have been the first to use pins in a truss of this character and to adopt the inclined end post, now in such common use.

In 1872 he published an enlarged edition of his book on bridge building, and a fourth edition was put out in 1883, including in this list of editions that of 1869, printed by himself. In 1866 he also pub-

lished, at Albany, N. Y., a pamphlet entitled "The Doctrine of Central Forces, Illustrated Without the Use of the Calculus."

Among his other inventions was a lifting draw-bridge, designed by him in 1873 to meet various difficult conditions found in carrying streets across the Erie Canal. The chief feature of this bridge was a counter-balanced floor suspended to an elevated trussed structure spanning the canal. When space was required for the passage of boats this floor was lifted by gears and shafting, sufficiently to allow the boats to pass beneath. He built one of these lift bridges in Utica, over the Erie Canal, and it is believed to be still in use.

Personally, Mr. Whipple was of a retiring disposition, preferring the quiet of his study and mechanical experiments to the society of any except his few most intimate friends. To the latter he was always genial and entertaining. From his youth upward he had an inveterate aversion to violence of any kind, and especially as this violence was exhibited towards the dumb creation. For this reason he had always abstained from animal food, except such as is produced in the dairy, and he published, in 1847, a small pamphlet called the "Way to Happiness," in which he ably defended his position and his peculiar diet. He claimed that his practice was in the interest of good health, rational economy and sound morality, and the fact that he was the last of a family of ten children and lived to a sturdy old age himself would seem to indicate that he found some virtue in his peculiar methods and views.

Squire Whipple was elected an Honorary Member of the American Society of Civil Engineers, on May 6th, 1868. He died at his home in Albany, N. Y., on March 15th, 1888, in his eighty-fourth year, leaving a widow but no children.

ALEXANDER DALLAS BACHE, Hon. M. Am. Soc. C. E.*

DIED FEBRUARY 17TH, 1867.

Alexander Dallas Bache, born at Philadelphia, July 19th, 1806, was the grandson of Richard Bache, Postmaster-General of the United States from 1776 to 1782, and a great-grandson of Benjamin Franklin. He was educated in a Philadelphia school and at the United States Military Academy at West Point. He was graduated at the head of his class, one of unusual ability, from the latter institution in 1825, and remained there for one year as an assistant professor. Subsequently he was assigned to duty at Newport, R. I., under Colonel Joseph G. Totten, Hon. M. Am. Soc. C. E., and while there married Miss Nancy Clarke Fowler.

* Memoir prepared from information furnished by A. T. Mosman, M. Am. Soc. C. E., and from papers on file at the House of the Society.

Leaving the army he went to Philadelphia as Professor of Natural Philosophy and Chemistry in the University of Pennsylvania, and then began a career as physicist and astronomer which soon brought him an international reputation. At that time the Franklin Institute had not been established very long, and he took an active part in the work which raised it to a prominent standing among scientific associations. He was also interested in the American Philosophical Society. In addition to the work connected with these societies and with the university, he was engaged in conducting investigations at his private observatory, where he determined for the first time in this country the periods of the daily variation of the magnetic needle, and by another series of observations the connection of the fitful variations of the direction of the magnetic force with the appearance of the aurora borealis. In 1836 he was elected President of the Board of Trustees of Girard College, and went abroad for the school to investigate European educational methods. This position he resigned six years later, as well as his connection with the free public school system of Philadelphia, and the High School of that city, which he had organized.

Although Prof. Bache's investigations in subjects connected with terrestrial magnetism had been of value to engineers, he was brought into more intimate relations with them in 1843, when he succeeded Mr. F. R. Hassler as Superintendent of the United States Coast Survey. What he accomplished in this office is indicated in a general way by the following extracts from a resolution passed on February 18th, 1867, at a meeting of his former assistants:

"Whatever of excellence there may be in the extended system of operations now carried on by the coast survey on every portion of our coast is due to Prof. Bache. He came to the charge of the work at a time when its operations were conducted upon a small scale and restricted to a limited portion of the coast. In a wonderfully short space of time he succeeded in winning the confidence of his official superior, and in securing the consent of Congress to a gradual enlargment of the work to its present scale. He called to his assistance men of thought and men of action from civil life, and from the army and navy, and with a rare felicity, discerning and applying the special aptitudes of each individual, he wrought out from discordant material a harmonious whole.

"He combined high administrative ability with vigor and energy in execution. While allowing and inviting free criticism of his plans during their inception, he exacted a rigorous accountability from the officers intrusted with their execution. Discipline under his administration was none the less real that it was not apparent.

"Prof. Bache was eminently just. The Coast Survey reports—those monuments of his fame—are full of evidence of the scrupulous care with which every officer serving under him received proper credit for his labors. His quick and ready appreciation of merit in every department of scientific inquiry and action, whether theoretic or practical, has been felt through the entire country, and has been of lasting benefit. To his fostering care and aid we owe the present perfection of the telegraphic method of obtaining longitude which recently achieved its crowning triumph in the determination by the Coast Sur-

vey of the precise difference of longitude between any two points in Europe and America, through the Atlantic cable."

Prof. Joseph Henry said, in his eulogy of him :

"When Prof. Bache took charge of the Survey it was still almost in its incipient stage, subjected to misapprehension, assailed by unjust prejudice, and liable, during any session of Congress, to be suspended or abolished. When he died, it had conquered prejudice, silenced opposition, and become established on a firm foundation as one of the permanent bureaus of the executive government."

His unusual administrative ability has been referred to particularly by most of his biographers. Prof. Fairman Rogers wrote* that he loved to put the machinery of his office together, wind it up, and then dismissing it all from his mind, hear the report at the designated time, when he would take up the thread of the matter just where he had left it last, as if he had thought of nothing else during the interval. "He understood thoroughly the way of doing nothing for himself that could be done for him by others, and thus reserved his time and powers for that work which he alone could do." Nevertheless, his early training in the details of observations was so thorough that interpolated figures are reported to have rarely escaped his notice, and his ability to tell an observer that on such a night he had omitted to examine the level of his instrument was little short of marvelous.

The Coast Survey was only one department of government work with which he was connected, for he was also, at one time or another, Superintendent of Weights and Measures, Lighthouse Commissioner and member of the Lighthouse Board, Regent of the Smithsonian Institute, and a Vice-President of the United States Sanitary Commission. The American Association for the Advancement of Science was founded largely through his influence, as was the National Academy of Science, and he was a president of both these organizations, as well as the American Philosophical Society. Foreign scientists recognized the importance of his work at an early period of his career, and he received many honors from European associations. His published works are many, and a list of them, outside of his official reports, would be too voluminous to print here.

At the request of the Governor of Pennsylvania, although overwhelmed with other public labors, he planned lines of defenses for Philadelphia during the civil war, and, to a certain extent, personally superintended their construction. Unaccustomed for many years to direct exposure to the sun, this work proved too much for his physical strength, and brought on the first indications of that malady which terminated his life.

Prof. Bache died at Newport, R. I., February 17th, 1867, and was buried in the Congressional Cemetery at Washington.

He was elected an Honorary Member of the American Society of Civil Engineers on March 2d, 1853.

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* *Journal* of the Franklin Institute, May, 1869.

ÉMILE MALÉZIEUX, Hon. M. Am. Soc. C. E.*

DIED MAY 20TH, 1885.

Émile Malézieux was born at St. Quentin, France, June 8th, 1822. He entered the École Polytechnique in 1841, and afterward the École des Ponts et Chaussées, from which he graduated in 1846, with next to the highest honors in the class.

After a short tour in England, he was placed in charge of a division, first of construction and later of maintenance, of the canal from the Marne to the Rhône, in the Departments of the Marne, the Meuse and the Meurthe. He held this post for twelve years, serving also during a part of this time on the construction of a portion of the railway from Paris to Strasburg, within the Department of the Meuse.

In 1859 he was assigned to duty in Paris in connection with the construction of the Belt Line Railway, a position he held for ten years. Toward the end of the next year he was also in charge of the canalization of the Marne, in the Department of the Seine, including the construction of the St. Maurice Canal and the Joinville Dam. At the Paris Exposition of 1867 he received a gold medal for the type of metal lock gates introduced by him on the St. Maurice Canal.

In 1868 Mr. Malézieux was appointed to a professorship at the École des Ponts et Chaussées, and was given the course in interior navigation, which he retained until 1877. His knowledge of public works led to his being sent in 1870 to this country to examine the works of American engineers. Here he collected a large amount of data, which was subsequently employed in the preparation of his two-volume report, entitled "Travaux publics en Amérique, en 1870." This was so satisfactory that the author was sent three years later on a similar mission to England, which resulted in the publication of another valuable report. These labors were not allowed to interfere with his regular work as a teacher, and, indeed, his original course was supplemented in 1871 by another on general methods of construction.

Early in 1877, his connection with the school was closed, and he was unanimously elected Secretary of the General Council of the Engineering Corps (Ponts et Chaussées), where he served with distinction until 1882. Then his health, feeble for several years, broke down, and he was given an indefinite furlough in which to recover. This enforced rest, although fully earned by continuous service since 1846, proved irksome to such an active man, and he applied for reinstatement. This was granted him, and his subsequent work showed no diminution in excellence. His death occurred suddenly on May 20th, 1885, his

* Memoir prepared from papers on file at the House of the Society.

rank in his corps at the time being that of Inspector-General of the Second Grade.

Mr. Malézieux was elected an Honorary Member of the American Society of Civil Engineers on November 3d, 1880. He was made a chevalier of the Legion of Honor in 1856, and an officer in 1874. He was also a member of the American Philosophical Society of Philadelphia and the Academic Society of St. Quentin.

McREE SWIFT, F. Am. Soc. C. E.*

DIED APRIL 5TH, 1896.

McRee Swift was born in New York City, April 19th, 1819. He was the son of General Joseph G. Swift, the first graduate of the United States Military Academy and formerly Chief of Engineers, United States Army, and Louisa M. Walker, daughter of James Walker, a rice planter of Wilmington, N. C.

After spending nearly a year at college, he was appointed in 1836 a junior assistant on the surveys of the Long Island Railroad, under General W. G. McNeill, Chief Engineer, and James P. Kirkwood, Past-President Am. Soc. C. E., Resident Engineer. Later in the same year he went to Fort Caswell, N. C., where he pursued professional studies under the direction of his brother, Alexander J. Swift, of the Corps of Engineers, United States Army. The next six years he spent in railway engineering in New England. He was engaged on the surveys and construction of the Boston and Albany (Western) Railroad under Major W. Whistler, Chief Engineer, and Captains William H. Swift and John Childe, Resident Engineers. Subsequently he served as Assistant Engineer under Frederick Harbach, Chief Engineer, on the surveys and construction of the Pittsfield and North Adams Railroad, and the extension of the New Haven and Hartford Railroad to Springfield, Mass.

In 1843 Mr. Swift was appointed to a more responsible position, that of Superintending Engineer of the Wilmington and Raleigh Railroad, extending from the Roanoke River to Wilmington, N. C., a distance of 160 miles. While connected with this company he began to substitute the T-rail for the old plate rail in general use at that time on southern railroads. In 1846 he came North to accept the position of Superintending Engineer of surveys and construction of the Newburgh branch of the New York and Erie Railroad under Major T. S. Brown, Chief Engineer, and served at the same time as commissioner for purchasing land for right of way. In 1849 and 1850 he was Superintending Engineer of the surveys and construction of 70 miles of the New

* Memoir prepared from information furnished by his family and from papers on file at the House of the Society.

York and Erie Railroad, from a point west of and near Hornellsville, N. Y., to a point below Olean, N. Y. Horatio Allen, Past-President Am. Soc. C. E., was Consulting Engineer for this work. In 1851 he was Chief Engineer of the surveys for the Rochester and Genesee Valley Railroad.

Mr. Swift went to Europe in 1851 with his father, and spent a year in traveling there. On his return he became Chief Engineer of the surveys and construction of the Rochester and Genesee Valley, and the Avon, Geneseo and Mount Morris Railroads. This work engaged his attention until 1856, when he became Engineer and Superintendent of a manufacturing and constructing company, of which he was subsequently elected President.

In 1874 Mr. Swift was elected a member of the Commission on Streets and Sewers of New Brunswick, N. J., and served as President of the Commission for eight years, when he resigned.

Mr. Swift's career was that of an able, upright and successful engineer during the infancy of the profession in this country, but, except to the few professional contemporaries who survive him, he has been best known as a man of affairs and a public-spirited citizen.

His relations, friends, and all who have been associated with him in the many business interests with which he was connected, benefited greatly by his example and his advice, based upon a keen intelligence, generosity and unswerving integrity, never to be forgotten by those who knew him.

The rare cultivation of mind and the manner and presence, which rendered him a typical gentleman of the old school, were combined with business ability of the first order.

All who knew him were benefited by his acquaintance and example, and will remember him as a type of what a Christian gentleman and loyal friend and fellow-citizen should be and can be, and yet consistently achieve success in a professional and business career.

Mr. Swift was the twenty-third member of the American Society of Civil Engineers. His name is among those on the original list of names proposed by the Board of Direction of the American Society of Civil Engineers and Architects, preserved in the Society House, and his membership dated from November 6th, 1852. He became a Fellow of the Society on March 9th, 1870. In 1888 he resigned from active membership, but he retained his interest in the Society to the last, and in a codicil to his will, drawn up a short time before his death, bequeathed the sum of $1 000 to the Society, the income to be devoted to the purchase of rare books and maps for its library and models for its museum. This gift was made in memory of his father, General Joseph G. Swift, who was chief engineer of many undertakings after his resignation from the army, among them the New Orleans and Pontchartrain Railroad in 1829, and the Harlem Railroad in 1832.

ROBERT BRIGGS, M. Am. Soc. C. E.*

DIED JULY 24TH, 1882.

Robert Briggs was a native of Boston, Mass., being born in that city on June 18th, 1822. His early education was obtained in the Boston public schools, and, while there, his aptitude for mathematics, which was afterwards one of his marked characteristics, was noticeable. His engineering training began at the age of seventeen, in the office of Alexander Parris, a local engineer and architect, where he remained for several years. His subsequent career was remarkable for the wide range of engagements it embraced. He designed and erected industrial plants of great size, and afterwards operated them, turning out a great variety of products, ranging from tubes to pumping engines. His practice as civil engineer was equally broad. In addition to the professional attainments which enabled him to carry on these works with marked success, he was a clear and ready writer on technical and scientific subjects, the author of several papers before engineering societies, and the editor, for a time, of a well-known scientific journal. The surprising thing is, that, with such versatility and such success in practical charge of important work, he was never a strong man, and was frequently invalided and prevented from putting into full play the unusual gifts he possessed.

From 1844 to 1847 Mr. Briggs was not engaged in engineering work, but in the latter year he worked for a few months on a railway line in Massachusetts. Then he became Constructing Engineer of the Glendon Rolling Mill, an important establishment then in course of construction at East Boston, and thus acquired his first taste of a branch of work in which he was destined to achieve a marked success in later years. When the mill was finished, he opened an office in Boston as a Consulting Engineer. This proved unprofitable, and he soon entered the service of Walworth & Nason, of Boston, with whom the application of steam to the warming of buildings in this country may be said to have originated. Mr. Briggs took a deep interest in this subject and in ventilation, and wrote several valuable papers on the subject, one of which was published in Volume X of *Transactions* of this Society. He took charge of the construction of the tube works of Walworth & Nason, and, when it was finished, served as its Superintendent for some time.

His restless nature compelled him to seek another field of work before long, and in 1852 he became Superintending Engineer of the firm

* Memoir prepared from information furnished by Henry G. Morris, M. Am. Soc. C. E., and papers on file at the House of the Society.

of Bird & Weld, later the Phœnix Iron Works, at Trenton, N. J. After a year in this place he moved to Mount Savage, Md., to become Superintendent of a rolling mill there, for a period of six months. Then he went to Troy, N. Y., as Superintendent of the Rensselaer Rolling Mill, a position he held for a year. After this experience in mechanical engineering, he turned his attention to civil engineering and architecture again, as Assistant Engineer under General M. C. Meigs. He was engaged on the construction of the Washington aqueduct, the dome of the Capitol at Washington, and the heating and ventilating systems of the halls of Congress. In connection with the last work he made an investigation into the proportions of rotary fans, the results of which were subsequently embodied in a paper presented to the Institution of Civil Engineers, and given the Watt medal and Telford premium of that society.

In 1857 he became a member of the firm of Nason, Dodge & Briggs, of New York, but this connection was brief, for in 1860 he went to Philadelphia as Superintendent and Engineer of the Pascal Iron Works of Morris, Tasker & Company. This position was the longest he ever held. The works were then comparatively disorganized, and his first labor was to bring them into a good condition for the manufacture of pipe, fittings, pipe-cutting machinery, gas works appliances, and the other specialties of the company. When this was done, he systematized all these products, placing this part of the business on an excellent footing, and designed and built new additions to the works.

One of the novel features introduced by Mr. Briggs in the construction of gas holders was the flat-top holder without interior trussing. The first structure of this type was built by him for Lewiston, Me. This method of construction, now recognized as being correct, was strenuously opposed and ridiculed at the time by many engineers and prominent builders of gas holders.

In 1866 he visited Europe for the company and made the acquaintance of many foreign engineers, especially in England, where his wide knowledge of American engineering works made him a welcome visitor in professional circles. When his connection with the Pascal Iron Works was terminated in 1869, he revisited England and increased his knowledge of English practice and widened the circle of friends he made on his previous stay in that country.

Early in 1871, he became Engineer and Superintendent of the Southwark Foundry, then owned by Henry G. Morris, M. Am. Soc. C. E. Here he designed and built many large pieces of machinery, including a pumping engine for the city of Lowell, Mass., which had a remarkably good duty for that time, sugar machinery, gas apparatus, blast furnace fittings, boilers, engines and similar heavy work. He designed and built a large foundry during his connection with Mr. Morris, and a 30-ton traveling power crane. He remained in this position

until the closure of the works in 1875 on account of the disturbance of the iron market at that time.

After a long illness which attacked him in 1875, Mr. Briggs made a short trip to England, returning to this country the next year to become editor of the *Journal* of the Franklin Institute, a post for which his wide experience and readiness as a writer made him particularly fitted. His work was well performed, but he wearied of it in a few years, and in 1878 opened an office in Philadelphia as a consulting engineer. This was not very profitable to him, but gave him time to prepare a number of valuable articles on technical subjects.

In 1880, he became Consulting Assistant to Col. William Ludlow, who was then in charge of river and harbor improvement in the vicinity of Philadelphia. He also retained his private practice, and was particularly interested in matters pertaining to heating and ventilating.

His health, never strong, began to fail noticeably in a short time, and late in 1881, after a brief visit to England, symptoms of paralysis appeared. He continued to work until April, 1882, when his physician made him desist and go to his mother's home in Dedham, Mass. His vitality was too exhausted, however, for him to recover, and he died there of paralysis on July 24, 1882, after a long and painful sickness.

The professional attainments of Mr. Briggs have been described as follows by Mr. Henry R. Towne, an intimate acquaintance.

"One of his most notable traits was the comprehensive scope of his knowledge, which covered almost the entire field of engineering, both civil and mechanical, and included much also of metallurgy, chemistry, architecture and the applied sciences. On almost any topic under these many heads he could discourse as a master with a minuteness and familiarity astonishing to any but those who knew what an extraordinary range was covered by his own personal experience in connection with mechanical and industrial operations, and who knew also how far these were supplemented by professional study and reading, continued uninterruptedly during the forty years of his business life. Added to these were advantages of a good early education and exceptional aptitude for mathematics, in which he excelled, and a very retentive memory."

Personally, Mr. Briggs had an even, quiet disposition, and a remarkable faculty for making and retaining friendships.

He was elected a Member of the American Society of Civil Engineers on October 19th, 1870.

WILMON W. C. SITES, M. Am. Soc. C. E.*

Died October 1st, 1885.

Wilmon W. C. Sites was born in 1849, and began his engineering career when he was nineteen years old as a rodman on the South Mountain Railroad. After spending about four months in this position, he entered the junior class of the Pennsylvania Polytechnic College, from which he was graduated in 1870.

From June, 1870, until February, 1871, he was rodman and assistant engineer on the construction of the Columbia and Port Deposit Railroad, a position he left to become Assistant Engineer of Surveys on the Stoney Creek branch of the North Pennsylvania Railroad. In a few months he resigned from this work and was appointed Assistant Engineer of the Berks County Railroad under Mr. J. Dutton Steele, and after the resignation of that gentleman, became Principal Assistant Engineer, a position he retained until the completion of the road in 1875.

In 1876 Mr. Sites removed to Jersey City, and commenced practice in general city engineering and surveying work, becoming Township Surveyor for West Hoboken and the Town of Union, in Hudson County, New Jersey, and superintending the construction of a number of public improvements in these places.

In 1877 he was appointed by Levi W. Post, M. Am. Soc. C. E., then Chief Engineer of the Jersey City Public Works Department, Surveyor in that department, having special charge of preparing a map of the water pipe systems of the city, proper knowledge of which was in a very confused state, the pipes having been laid at different periods by different municipal bodies, which in 1870 were united to form the present city, and no record having been preserved.

In 1879 a change of political control resulted in the appointment of a new chief engineer, and Mr. Sites returned to private practice.

In 1881 he was appointed Chief Engineer of the Public Works Department, and held the office until the spring of 1884. During this time he completed the second high-service distributing reservoir on Jersey City Heights, which had been commenced in 1871. Bringing this reservoir into use enabled him to draw down and clean the old reservoir, which had been in constant use for thirty years. He also laid the main supplying Bayonne City with water from the Jersey City works.

During Mr. Sites' term of office the deterioration of the water of the Passaic River at Belleville became a serious menace to the prosperity

* Memoir prepared by E. W. Harrison, M. Am. Soc. C. E.

of Jersey City and Newark. The two cities combined in efforts to prevent the growth of the evil, and made an unsuccessful attempt to secure legislation to that end. Mr. Sites, as Chief Engineer of the Jersey City Department, took a very active part in the necessary investigations and preparations of evidence to sustain the cities' side of the agitation.

In 1884, on a change of administration, Mr. Sites resigned his office and entered into partnership with Edlow W. Harrison, M. Am. Soc. C. E., as engineers and surveyors.

The Legislature of 1884 had passed an act entirely revolutionizing the system of taxation of railroad and canal property in the State. The enforcement of the act was combated by all of the great transportation companies having interests in New Jersey. By the provisions of the act, which is now the settled system of taxation for this class of property in the State, the roads were required to be valued for assessment at their true value, and one of the elements of value was determined to be the cost of reproduction, less deterioration.

The new firm was selected by the State Board of Assessors, the body charged with the execution of this law, to act as the engineers for the State in the valuation of the railroad properties. In this work Mr. Sites was engaged until his death. The labor entailed was incessant. Not only was the field work of measurement of quantities and fixing market values of all the innumerable details which go to make up a railroad plant, and called for the supervision of a large corps of assistants, to be carried forward, but at the same time the attacks in the courts made by the companies upon the values as fixed and determined had to be met and answered. The examinations and cross-examinations of the members of the firm occupied many days. For over a year the work required fifteen or more hours out of the twenty-four.

Mr. Sites was never a healthy man, and, while Chief Engineer of the city, had shown symptoms of consumption. His perseverance was remarkable, and toward the end of his labor, he spent many days at active work, when another man would have been in bed.

Mr. Sites did not live to see the full completion of the work he had been engaged upon, and the establishment of its correctness by the highest courts of the State. Of him it may be truly said, "he died in harness," for within a week of his death, while lying upon the bed from which he never rose, he advised with his partner on the details of the engineering work of the cases then under consideration in the courts.

Mr. Sites was elected a Member of the American Society of Civil Engineers November 6th, 1878.

WILLIAM ALBERT ALLEN, M. Am. Soc. C. E.*

DIED MARCH 21st, 1896.

William Albert Allen was born at Bath, Me., October 18th, 1852. He graduated in 1874 from the Maine State College, where he studied civil engineering, and a year later entered the service of the Maine Central Railroad Company as assistant engineer. At that time the policy the management of this company was rapidly adopting aimed at the construction of a modern, high-class road-bed with good iron bridges, and Mr. Allen's attainments made him a valuable man for such work. In April, 1877, he was made Civil Engineer of the road, and in January, 1885, was promoted to the position of Chief Engineer, with the control and responsibility that the title implies. In 1887 and 1888 he was also Chief Engineer of the Portland Union Railway Station Company, and held the office from the commencement of the work until the completion of the station, train-shed and approaches.

Mr. Allen lost his life on March 21st, 1896, while inspecting work that was being done on the railway bridge between Auburn and Lewiston. He was leaning out from the steps of a car to observe the progress of the work, when he lost his hold or was struck by a telegraph pole. He fell from the car to the bridge, from which he dropped into the river above the falls at this place. He was carried over the falls and his body was never recovered. He was a widower and left no children.

Mr. Allen was elected a Member of the American Society of Civil Engineers, May 6th, 1891.

ORLANDO BELINA WHEELER, M. Am. Soc. C. E.†

DIED JUNE 3D, 1896.

Orlando Belina Wheeler was born at Lodi, Mich., November 29th, 1835. He graduated from the University of Michigan in 1862, and then became acting assistant under Dr. F. Brünnow in the observatory of that institution. From 1863 to 1871 he was in charge of astronomical and geodetical triangulation parties on the United States Lake Survey, and from 1871 to 1878 was in charge of the computing division of the same survey. He made a specialty of astronomy, and while with the Lake Survey was sent as Assistant Astronomer by the United States Government to Siberia, to observe the transit of Venus in 1874, and to Colo-

* Memoir prepared from information furnished by Mr. H. C. Robinson, Assistant Engineer Maine Central Railroad, and from papers on file at the House of the Society.

† Memoir prepared from information furnished by B. H. Colby, M. Am. Soc. C. E., and from papers on file at the House of the Society.

rado in 1878 on the total eclipse expedition of that year. In 1882 he was again sent by the Government as Assistant Astronomer with the expedition that went to Patagonia to observe the transit of Venus. Mr. Wheeler was the first to use the Morse alphabet in solar telegraphy, a method of communication he established while engaged in the triangulation of the Great Lakes.

After completing his astronomical work for the Government, he made a tour of the world, returning to this country in 1885 to become Principal Assistant Engineer in the office of the Missouri River Commission at St. Louis, Mo. This engagement continued until his death from apoplexy on June 3d, 1896, after an illness of but ten hours.

In social life Mr. Wheeler was gentle and unassuming, his quiet manner, quick intellect and learning making him beloved by all. He leaves a widow, one daughter and three sons.

Mr. Wheeler was elected a Member of the American Society of Civil Engineers on November 2d, 1887.

LOUIS ROBERTS WALTON, M. Am. Soc. C. E.*

Died November 9th, 1885.

Louis Roberts Walton was born in Chester County, Pennsylvania, November 24th, 1842. He graduated from the Polytechnic College of the State of Pennsylvania in the class of 1863, and soon afterwards entered the employ of the Philadelphia and Erie Railroad Company, being connected with the harbor improvements at Erie, Pa. He remained with this company for four years, and then became Resident Engineer on construction of the Baltimore and Potomac Railway Company. In 1872 he was again employed on the Philadelphia and Erie Railroad, this time as Resident Engineer on construction, and the following year he went to the Pittsburg, St. Louis and Chicago Railroad Company as Principal Assistant Engineer.

In 1881 he accepted the position of Engineer of the St. Bernard Coal Company, of Earlington, Ky., the largest corporation of the kind in the State, and a pioneer in the introduction of improved mining machinery. He remained with this corporation until his death on November 9th, 1885. As an engineer he was careful, accurate and energetic. Coal-cutting machinery was just introduced into the mines at the time he became connected with the St. Bernard Company, and much of the success accomplished by the machines is due to his efforts. As a man and a citizen none stood higher. In his death the Society lost a most honorable member.

Mr. Walton was elected a Member of the American Society of Civil Engineers on April 1st, 1885.

* Memoir prepared by John B. Atkinson, M. Am. Soc. C. E.

ROBERT LINAH COBB, M. Am. Soc. C. E.*

Died June 2d, 1895.

Robert Linah Cobb was born at Cumberland Iron Works, Tenn., on March 5th, 1840. He was educated in the local schools and at Stewart College, now the Southwestern University, and after the completion of his studies, became a rodman on the Memphis, Clarksville and Louisville Railroad, now part of the Louisville and Nashville system. He soon became Assistant Engineer on this road, and in 1859 and 1860 was City Engineer of Clarksville, Tenn.

On the outbreak of the war he offered his services to the Confederacy and was assigned to the ordnance department. He was ordered to Fort Donelson, and, after the surrender of that post, reported to General Johnson at Nashville. Captain Cobb was then assigned to the engineering department and ordered to Corinth. The service he rendered as a military engineer was characteristic of the man, always faithful, painstaking, tireless and courageous. He was never taken prisoner, and served continuously until the close of the war.

After the completion of this experience, he became Division Engineer of the Memphis, Clarksville and Louisville Railroad, and in 1867 was appointed Chief Engineer of the Winchester and Alabama Railroad, now part of the Louisville and Nashville system. Two years later he became Assistant Engineer of the Memphis and Ohio Railroad, from which he went in 1869 as Division Engineer to the Memphis and Little Rock Railroad, where he remained until 1872, serving part of the time as Acting Chief Engineer. In 1873 he conducted mining operations at Kellogg, Ark., and later in Mexico, but returned to railroad work in 1876 as a member of the engineering staff of the Little Rock and Fort Smith Railway. In 1881 and 1882 he was Chief Engineer of the Texas and St. Louis Railway, now the St. Louis, Arkansas and Texas. The next four years were spent in manufacturing machinery at Little Rock, Ark. In 1886 Captain Cobb was appointed Chief Engineer of the Indiana, Alabama and Texas Railroad, and upon the absorption of that line in 1887 by the Louisville and Nashville Railroad Company, he was retained by the latter company as Chief Engineer of construction, a position he held at the time of his election as a Member of the American Society of Civil Engineers on January 2d, 1890. In this year he was appointed Chief Engineer of the Clarksville Mineral Railroad, and in 1892 went to Ohio as the Chief Engineer of the Ohio Southern Railroad. Upon the completion of his work on this

* Memoir prepared by E. C. Lewis, M. Am. Soc. C. E.

line he removed his headquarters to Cleveland, where, in the winter of 1894, he had an attack of grip from which he never recovered. He returned to the South in May, 1895, and died on June 2d at his early home, Clarksville.

His life's work speaks for him professionally. Personally he was at once a loyal friend and a chivalrous foe. He was married in 1877, and was left a widower ten years later. One son survives him.

HENRY D. BLUNDEN, M. Am. Soc. C. E.*

Died January 7th, 1889.

Henry D. Blunden was born at Poling, England, April 8th, 1849. He was educated at Brighton and London, England, and at the age of 16 years was articled to John Lawson, C. E., for a term of four years. During 1869 and 1870 he was employed as Contractor's Engineer on the construction of the Mansfield and Southwell Branch of the Midland Railway, England. From August, 1870, to July, 1872, he was Assistant Engineer on the Kansas Pacific Railway, making preliminary surveys and locating new towns; from July, 1872, to July, 1873, Assistant Engineer on the Leavenworth, Lawrence and Galveston Railway, making preliminary surveys and building machine shops; from July, 1873, to 1882, Assistant Engineer on the New York, Lake Erie and Western Road. During 1882 and 1883 he was Road Master on the Eastern Division of the Erie Road, and on September 13th, 1883, he was appointed Engineer of Maintenance of Way of the same road, holding this position until 1886. During 1887 and 1888 he was Assistant Engineer at the Union Bridge Company's shops at Athens, Pa., and was also during this time Superintendent of Bridges on the Pennsylvania and New York Railway, and the Geneva, Ithaca and Sayre Railway. His death occurred January 7th, 1889.

Mr. Blunden was elected a Junior of the American Society of Civil Engineers on January 5th, 1876, and a Member on February 4th, 1880.

* Memoir prepared by W. B. Coffin, M. Am. Soc. C. E.

RUSSELL WADSWORTH HILDRETH, Jun. Am. Soc. C. E.*

DIED DECEMBER 23D, 1895.

Russell Wadsworth Hildreth was born in New York City on February 12th, 1865. He entered the School of Mines at Columbia College in 1881, and was graduated in June, 1885, with the degree of Engineer of Mines. Four months later he became a draftsman in the New York office of George S. Morison, Past-President Am. Soc. C. E., remaining there until March 1st, 1886, when he went to the Buffalo shops of the Union Bridge Company. There he was engaged in the inspection of the double-track and highway bridge across the Missouri River at Omaha, Neb., for the Union Pacific Railway Company, and two bridges for the Oregon Railway and Navigation Company. From April 1st to August 1st, 1887, he was Assistant Engineer on the Union Pacific Bridge at Omaha, and then went to the Athens shops of the Union Bridge Company to take charge of the inspection of a bridge across the Willamette River at Portland, Ore., for the Oregon Railway and Navigation Company.

On January 1st, 1886, the firm of Hildreth and Nettleton, inspectors of bridges, was formed by Mr. Hildreth and Mr. W. A. Nettleton. On September 1st, 1888, this firm became R. W. Hildreth and Company, owing to the withdrawal of Mr. Nettleton and the association of Mr. P. S. Hildreth. Mr. Hildreth was connected with it up to the time of his death.

The work carried on embraced the inspection of many well-known bridge structures during manufacture and erection, including the New London and Red Rock bridges, general work for many of the principal cities, railroads and other corporations, and the preparation and examination of plans for steel work and the inspection of existing structures.

Mr. Hildreth was elected a Junior of the American Society of Civil Engineers on January 4th, 1888. He was a member of the American Society of Mechanical Engineers, the American Institute of Mining Engineers, and the Engineers' Club of New York. He died of typhoid fever and heart failure, after a brief illness.

* Memoir prepared from information furnished by Mr. P. S. Hildreth and from papers on file at the House of the Society.

VERNON HILL GRIDLEY, Jun. Am. Soc. C. E.*

Died September 17th, 1896.

Vernon Hill Gridley was born on a farm near Owosso, Mich., on February 11th, 1867. His early education was received in the country schools most convenient to his home. When he was twelve years of age the family left Michigan and settled in Monroe County, New York. From 1885 to 1887 he attended the Normal School at Brockport, and during the winter of 1887–88 he took the course in the Rochester Business University. The following year he had charge of the commercial department of a college or high school in Toronto, Canada, and after serving one year there he assumed a similar position in Fairfield Academy, Herkimer County, New York. In September, 1890, he entered the Rensselaer Polytechnic Institute, from which he was graduated with the degree of Bachelor of Science in 1893. He remained another year at the Institute, assisting Prof. Wm. P. Mason with his classes in chemistry, and in June, 1894, received the degree of Civil Engineer.

The first work which he did after leaving Troy was the taking of observations and the determination of the flow of water at the outlet of Lake George at Ticonderoga. In September he was appointed a leveler in the Department of City Works, Brooklyn, N. Y., and was employed in running a series of levels to determine the actual elevations of all the improved streets in the city. Early in 1895 he entered a competitive examination for assistant engineers in that department, in which he obtained high rank, and was at once appointed. From then until the time of his death he was engaged upon the construction of street pavements in the city of Brooklyn.

He was elected a Junior of the American Society of Civil Engineers on February 4th, 1896.

He contracted typhoid fever in August, 1896, and died at St. Mary's Hospital, Brooklyn, on September 17th, 1896.

Mr. Gridley's brief professional career gave promise of a bright future. Quiet in manner and reserved in disposition, he impressed all who came in contact with him as a man of force and character. His industry, integrity and capability would have insured success in any field. His thoroughness in all matters of detail and his marked business capacity rendered his services especially valuable, both in designing and executing engineering work, while his admirable personal qualities won him many friends, who have learned of his untimely death with the keenest regret.

* Memoir prepared by N. P. Lewis, M. Am. Soc. C. E.

WILLIAM ALEXIS GEORGE EMONTS, Jun. Am. Soc. C. E.*

Died November 5th, 1887.

William Alexis George Emonts was born in 1847, at Spire, Bavaria, and was educated in the gymnasium at that place. He served as a lieutenant in the Bavarian army in the wars of 1866 and 1870–71, and during this time studied and practiced military engineering somewhat.

Soon after the close of the Franco-German war he came to this country, and in February, 1873, became an instrument man in the Engineering Corps of the Philadelphia and Reading Railroad. In the fall of 1874 he became assistant to Mr. Henry W. Potts, Division Engineer on the Philadelphia and New York New Line Railroad, and retained this position until the completion of construction in June, 1876. He then became Assistant Engineer and Draftsman on the North Pennsylvania Railroad. In 1876 Mr. Emonts went to Germany and in 1879 to Central America.

During 1882 and 1883 he was engaged on the construction of the Shamokin, Sunbury and Lewisburg Railroad, and was located at Sunbury. During the latter part of 1883, he went to Philadelphia and was engaged on the surveys of the Schuylkill River East Side Railroad, until the conclusion of that work, some time in 1884. About 1885 he published a small pamphlet containing metric conversion tables.

Mr. Emonts was elected a Junior of the American Society of Civil Engineers on September 6th, 1876.

* Memoir prepared from information furnished by D. McN. Stauffer, Theodore Voorhees and William Hunter, Members Am. Soc. C. E., and from papers on file at the House of the Society.

Vol. XXII. NOVEMBER, 1896. No. 9.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Edited by the Secretary, under the direction of the Committee on Publication.

CONTENTS.

SOCIETY AFFAIRS.

PAPERS.

The price of publications is as follows: Proceedings, $6 per annum; Transactions, $10 per annum. Postage will be added when they are sent to foreign countries.

American Society of Civil Engineers.

OFFICERS FOR 1896.

President, THOMAS C. CLARKE.

Vice-Presidents.

Term expires January, 1897:
DESMOND FITZGERALD,
BENJAMIN M. HARROD,

Term expires January, 1898:
WILLIAM R. HUTTON.
P. ALEXANDER PETERSON.

Secretary, CHARLES WARREN HUNT.

Treasurer, JOHN THOMSON.

Directors.

Term expires January, 1897:	*Term expires January*, 1898:	*Term expires January*, 1899:
WILLIAM H. BURR,	AUGUSTUS MORDECAI,	GEORGE A. JUST,
JOSEPH M. KNAP,	CHARLES SOOYSMITH,	WM. BARCLAY PARSONS,
BERNARD R. GREEN,	GEORGE H. BENZENBERG,	HORACE SEE,
T. GUILFORD SMITH,	GEORGE H. BROWNE,	JOHN R. FREEMAN,
ROBERT B. STANTON,	ROBERT CARTWRIGHT,	DANIEL BONTECOU,
HENRY D. WHITCOMB.	FAYETTE S. CURTIS.	THOMAS W. SYMONS.

Assistant Secretary, JOHN M. GOODELL.

Standing Committees.

The President of the Society is *ex-officio* Member of all Committees.

On Finance:	*On Publications:*	*On Library:*
JOSEPH M. KNAP,	WILLIAM H. BURR,	T. GUILFORD SMITH,
HORACE SEE,	JOHN THOMSON,	ROBERT B. STANTON,
WM. BARCLAY PARSONS,	ROBERT CARTWRIGHT,	AUGUSTUS MORDECAI,
F. S. CURTIS,	DESMOND FITZGERALD,	DANIEL BONTECOU,
JOHN R. FREEMAN.	HENRY D. WHITCOMB.	CHARLES WARREN HUNT.

Special Committees.

On Uniform Standard Time:—Sandford Fleming, Charles Paine, Theodore N. Ely, J. M. Toucey, T. Egleston.

On Analysis of Iron and Steel:—Sub-Committee of the American Society of Civil Engineers (of the International Committee on Standards for the Analysis of Iron and Steel, of which Prof. J. W. Langley is Chairman)—Charles B. Dudley, William Metcalf, Thomas Rodd, A. E. Hunt.

On Units of Measurement:—George M. Bond, William M. Black, R. E. McMath, Charles B. Dudley, Alexander C. Humphreys.

The rooms of the Society are open from 9 to 17 o'clock each business day, except Saturday (when they are closed at 15 o'clock), and at other times on application to the Janitor.

House of the Society—127 East Twenty-third Street, New York.

Vol. XXII. NOVEMBER, 1896. No. 9.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS.

CONTENTS:

MINUTES OF MEETINGS.

OF THE SOCIETY.

November 4th, 1896.—The meeting was called to order at 20.15 o'clock, L. L. Buck, M. Am. Soc. C. E., in the chair; Charles Warren Hunt, Secretary, and present, also, 53 members and 8 guests.

The minutes of the meetings of October 7th and 21st, 1896, were adopted as printed in *Proceedings* for October, 1896.

Upon motion by Edward P. North, M. Am. Soc. C. E., duly seconded, it was unanimously voted, in accordance with Article VI, Section 13, of the Constitution, to recommend to the Board of Direction the consideration of the appointment of a committee to report on the proper manipulation of tests of cement.

A paper entitled "Experiments on the Protection of Steel and Aluminum Exposed to Sea Water," was presented by A. H. Sabin, Assoc. M. Am. Soc. C. E., and discussed by Messrs. F. T. Bowles, Wm. Barclay Parsons, M. R. Sherrerd, W. M. Stiles, R. D. Upham and A. H. Sabin. A communication on the subject from Foster Crowell, M. Am. Soc. C. E., was read by the Secretary.

Ballots were canvassed and the following candidates declared elected:

As Members.

Loomis Eaton Chapin, Canton, O.
William Cushing Edes, San Francisco, Cal.
William Voorhees Judson, Galveston, Tex.
Francis John Llewellyn, Minneapolis, Minn.
Frederic Albert Molitor, South McAlester, Ind. Ter.
George Washington Vaughan, Cleveland, O.

As Associate Members.

Frank Lynton Chase, Louisville, Ky.
George Lewis Christy, New York City.
Henry Stilson Farquhar, Baltimore, Md.
Andrew Ernest Foyé, New York City.
Lewis Elisha Johnson, Steelton, Pa.
Frederick Beecher Lawton, New York City.
Charles Benjamin Wing, Stanford University, Cal.

The Secretary announced the election by the Board of Direction on November 3d, 1896, of the following candidates:

As Juniors.

Frank William Allen, New York City.
William Stewart Harding, Philadelphia, Pa.
Alexander Haring, Troy, N. Y.
Edward Fulbister Kenney, Elkton, Md.
Frank Curtiss Schmitz, Pittsburg, Pa.
John Henry Stewart, New York City.

Adjourned.

November 18th, 1896.—The meeting was called to order at 20.15 o'clock, Director John R. Freeman in the chair; Charles Warren Hunt, Secretary, and present, also, 70 members and 15 guests.

A paper by George E. Gray, Hon. M. Am. Soc. C. E., entitled "Notes on Early Practice in Bridge Building," was read by the Secretary, who also presented correspondence on the subject from Messrs. E. B. Cushing and T. Kennard Thomson. The paper was discussed by Messrs. G. H. Thomson, G. H. Blakeley, G. R. Hardy, James Owen and John R. Freeman.

A paper by Charles Carroll Gilman, F. Am. Soc. C. E., entitled "Experiments with a New Method of Heating and Ventilation," was read by the Secretary.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

November 3d, 1896.—Five members present.

Messrs. Ira A. Shaler, Herbert W. York and Charles Warren Hunt were appointed a committee to take charge of the arrangements for the Annual Meeting.

Applications were considered, and other routine business transacted.

Six candidates were elected as Juniors.

Adjourned.

ANNOUNCEMENTS.

LIBRARY.

On January 2d, 1894, a petition was received by the Board of Direction from a number of members requesting that the Library be opened every Wednesday evening for the benefit of those members who could not consult it at other times. The request was granted, and the Library has been opened once every week since that date. There have never been more than five members of the Society present on any Wednesday evening, seldom as many as three, sometimes only one, and lately none. The Board, however, is desirous of making a further experiment in the matter, and has authorized the Secretary to open the Library every evening during the months of November and December, for the purpose of ascertaining whether members will avail themselves of the opportunity thus given. A record of the attendance will be kept, and the future policy in this matter will be largely governed by the result.

MEETINGS.

Wednesday, December 2d, 1896, at 20 o'clock, a regular meeting will be held, at which a paper by M. S. Parker, M. Am. Soc. C. E., entitled "Governing of Water Power under Variable Loads" will be presented. This paper was printed in *Proceedings* for October, 1896, already published.

Wednesday, December 16th, 1896, at 20 o'clock, a regular meeting will be held, at which two papers, one by Edward P. North, M. Am. Soc. C. E., entitled "The Influence of Rails on Street Pavements," and the other by James Owen, M. Am. Soc. C. E., entitled, "Car Tracks and Pavements," will be presented and jointly discussed. The papers are printed in this number of *Proceedings.*

DISCUSSIONS.

Discussion on the paper by George S. Morison, Past-President Am. Soc. C. E., entitled "Suspension Bridges—A Study," which was presented at the meeting of October 21st, will be closed December 1st.

Discussion on the paper by A. H. Sabin, Assoc. M. Am. Soc. C. E., entitled "Experiments on the Protection of Steel and Aluminum Exposed to Sea Water," which was presented at the meeting of November 4th, will be closed December 15th.

Discussion on the paper by George E. Gray, Hon. M. Am. Soc. C. E., entitled "Notes on Early Practice in Bridge Building," and the paper by Charles Carroll Gilman, F. Am. Soc. C. E., entitled "Experiments with a New Method of Heating and Ventilation," which were presented at the meeting of November 18th, will be closed January 1st, 1897.

Discussion on the paper by M. S. Parker, M. Am. Soc. C. E., entitled "Governing of Water Power under Variable Loads," which will be presented at the meeting of December 2d, 1896, will be closed January 15th, 1897.

Discussion on the paper by Edward P. North, M. Am. Soc. C. E., entitled "The Influence of Rails on Street Pavements," and the paper by James Owen, M. Am. Soc. C. E., entitled "Car Tracks and Pavements," which will be presented at the meeting of December 16th, 1896, will be closed February 1st, 1897.

MEMOIRS OF DECEASED MEMBERS.

It is gratifying to announce that the request for information concerning the career of deceased members of the Society, made in *Proceedings* for October, has resulted in securing data for several memoirs, which appear elsewhere in this issue. In the case of a number of the members named in the list already published, considerable information has been received, but not enough for memoirs. Hence, the request is renewed that any information or notes, however meager, relating to the career of the deceased members named in the following list be forwarded to the Secretary:

MEMBERS.

Name.	Date of Election.	Date of Death.
William Young Arthur	Dec. 4, 1867	Feb. 15, 1876
William Grain	Sept. 15, 1869	June 10, 1877
H. Grassau	July 6, 1853	May 16, 1870
Theodore D. Judah	May 4, 1853	Unknown.
J. W. P. Lewis	Jan. 15, 1853	Unknown.
William H. Morrell	Nov. 5, 1852	Unknown.
William W. Morris	Jan. 5, 1853	Unknown.
Thomas S. O'Sullivan	Jan. 5, 1853	Nov. 1, 1855
Simeon Sheldon	Feb. 5, 1873	Mar. 4, 1883

ASSOCIATE.

Name.	Date of Election.	Date of Death.
EDWARD WHEATON	Mar. 3, 1880	Mar. 6, 1889

FELLOWS.

Name.	Date of Election.	Date of Death.
GEORGE W. CASS	Mar. 30, 1871	Mar. 21, 1888
MILTON COURTWRIGHT	June 11, 1870	April 25, 1883
WILLIAM WILLIAMS	June 16, 1870	Sept. 10, 1876
J. BUTLER WRIGHT	May 24, 1870	Oct. 31, 1877

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

Name	Address	Date of Membership.
BELL, JAMES RICHARD	4 Addison Court Gardens, Hammersmith, London, W., England	Sept. 2, 1886
BROWN, GILLMOR	Wheeling, W. Va.	May 6, 1896
CHAPIN, LOOMIS EATON	City Engineer, City Hall, Canton, Ohio — Jun. / Assoc. M. / M.	Dec. 3, 1884 / Sept. 7, 1892 / Nov. 4, 1896
HOOD, WILLIAM	4 Montgomery St., San Francisco, Cal.	Oct. 7, 1896
HUTTON, NATHANIEL HENRY	Harbor Board Office, Baltimore, Md.	June 3, 1896
JUDSON, WILLIAM VOORHEES	1st Lieut. Corps of Engrs., U. S. A., Galveston, Tex.	Nov. 4, 1896
KING, WILLIAM BYRD	Fort Worth, Tex.	Oct. 7, 1896
MARX, CHARLES DAVID	Stanford University, Santa Clara Co., Cal.	Oct. 7, 1896
MOLITOR, FREDERIC ALBERT	South McAlester, Indian Territory	Nov. 4, 1896
SCHOFIELD, HIRAM ABIF	1021 Edgmont Ave., Chester, Pa.	Oct. 7, 1896
TAYLOR, HARRY	Capt. Corps of Engrs., U. S. A., Seattle, Wash.	Oct. 7, 1896
THOMPSON, WILLIAM ANDREW	La Crosse, Wis.	Oct. 7, 1896

ASSOCIATE MEMBERS.

Name	Address	Date of Membership.
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			Date of Membership.
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FOYÉ, ANDREW ERNEST	163 West 79th St., New York City	Jun. Assoc. M.	May 2, 1893 Nov. 4, 1896
JACOB, ALBERT PETER	Engr. of Construction, Board of Education, New York City, 146 Grand St., New York City		Oct. 7, 1896
JOHNSON, LEWIS ELISHA	Steelton, Pa.		Nov. 4, 1896
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LOCKWOOD, WILLARD DATUS	6 Brighton Ave., Rochester, N. Y.	Jun. Assoc. M.	Apr. 3, 1894 Oct. 7, 1896
MICHIE, WILLIAM ROBERTS	Greensburg, Pa.		Oct. 7, 1896

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BIGELOW, WILLIAM DANA	Care of Post & McCord, 289 Fourth Ave., New York City	Oct. 6, 1896
GARTENSTEIG, CHARLES	112 East 81st St., New York City	Oct. 6, 1896
LATTING, BENJAMIN FRANKLIN	424 Quincy St., Brooklyn, N. Y.	Oct. 6, 1896
ORMSBY, FRANK GORDON	Easton, Pa.	May 5, 1896
STEWART, JOHN HENRY	123 West 11th St., New York City	Nov. 3, 1896

CHANGES AND CORRECTIONS.

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McCarty, Richard J. .... Gen. Mgr. Augusta Ry. and Electric Co., Dyer Bldg., Augusta, Ga.

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Taussig, Hubert Primus .... 322 Wainwright Bldg., St. Louis, Mo.

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Wada, Yoshichika .... Chf. Engr. Chin-Yetsu Ry., No. 39 Shimamura, Saba-gori, Gunbaken, Japan.

Williamson, Sydney Bacon .... U. S. Asst. Engr., Muscle Shoals Canal, Florence, Ala.

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French, Charles Augustus .... 197 Lincoln St., Marlboro', Mass.

Polledo, Ysidoro .... Apartado 147, Matanzas, Cuba.

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Tappan, Roger .... 249 Barkeley St., Boston, Mass.

Walker, Elton David .... 16 Gillespie St., Schenectady, N. Y.

Worden, Beverly Lyon .... 706 Pabst Bldg., Milwaukee, Wis.

DEATH.

Joy, James F. .... Elected Fellow November 6th, 1872; died September 24th, 1896.

ADDITIONS TO

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1896. NOVEMBER. No. 9.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CONTENTS:

THE INFLUENCE OF RAILS ON STREET PAVEMENTS.

By EDWARD P. NORTH, M. Am. Soc. C. E.

TO BE PRESENTED DECEMBER 16TH, 1896.

When the streets of cities were paved with granite or trap blocks, laid on a sand foundation, with a space varying from 1 in. to 2 ins. between the blocks, which was thought necessary to afford a foothold for the horse traffic, the section of the rail selected by surface railroad

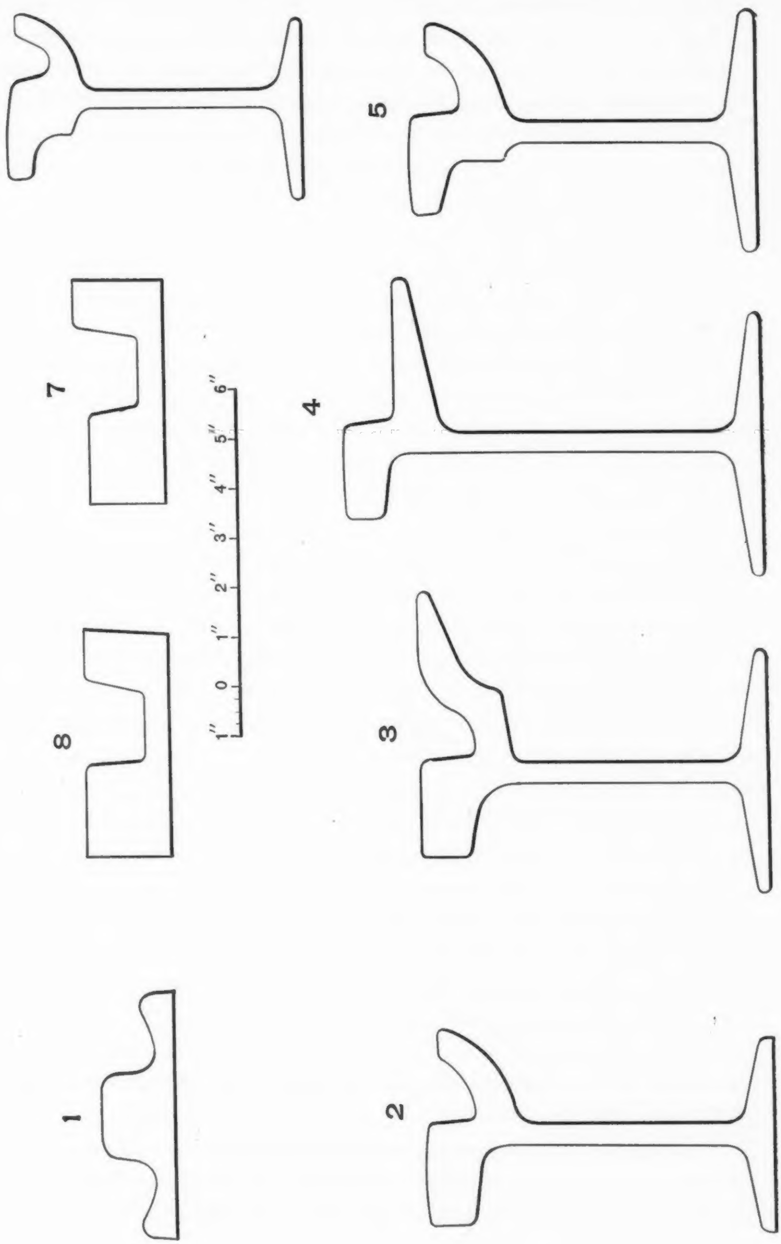
NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

companies did not add materially to the unevenness of the pavement. As a matter of fact, the first rails used were so much of an improvement on the prevalent street pavements that the traffic early developed a tendency to follow the lines of the rails. As this retarded the railroad traffic through a natural unwillingness on the part of teamsters to pull out of the track, the Hewitt or center-bearing rail (Fig. 1) was invented, with the avowed purpose of preventing vehicular traffic following the lines of the rails. While this rail is probably as obstructive to traffic crossing it at a sharp angle as any street rail ever invented, its very brutality partially defeated its object, as a heavily loaded wagon once on the line of such rails leaves it with extreme reluctance. It is, however, largely employed on the surface roads of the City of New York, and it has required an act of the legislature to prevent a further extension of its use. A modification of this rail (Fig. 9) has also been introduced, and is used as a girder rail on one of the cable lines.

The side-bearing rail shown in Fig. 4 as a girder rail presents a very good wheelway for vehicles once between the rails, and thus far is better than the Hewitt rail; but on account of its nearly vertical sides, it is very hard to pull a loaded wagon out of the track, and in crossing at a small angle with a light vehicle at any speed, the jerk is about as severe as on the center-bearing rail. A rail of this section is also used as a strap rail, being spiked to longitudinal stringers, as is the center-bearing rail generally.

Figs. 7 and 8 show sections that are employed as guard rails on curves and otherwise. They also are strap rails, and when laid on curves, it is almost impossible to make the spikes hold so well that water will not splash out from under them. The only excuse for their use is that bending them costs less than bending a girder rail, and, in general, the use of a strap rail on any highway should be prohibited after a near date in all self-respecting countries.

When permission was given to lay a cable road on Broadway, in New York City, both the previously mentioned forms of rail were so strenuously objected to that the Commissioner of Public Works prescribed a grooved rail, as shown in Fig. 5. This was followed on the Third Avenue line by a rail shown in Fig. 2, and on the Twenty-eighth and Twenty-ninth Street road the section shown in Fig. 6 was adopted. All of these rails are improvements on any of the forms of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rails before mentioned, but all of them are objectionable in that the flange is lower than the tread, which results in an unnecessary unevenness in the pavement, and in Fig. 6 the slot is so narrow and the sides so steep that there is difficulty in keeping it clean.

In the spring of 1895, the Metropolitan Traction Company, intending to lengthen its lines materially, presented to the Commissioner of Public Works, through the Hon. John D. Crimmins, at that time its managing director, a form of rail which, after some slight modification, was adopted. It is shown in Fig. 3. Except that the rail should have been 9 ins. deep, instead of only 7, this section is possibly the best that has been introduced in this country.

There is abundant depth for the wheel flanges, while the curved flange on the rail allows obstructions to pass out easily, and materially aids a narrow-tired carriage wheel in getting out, as, the moment it assumes any angle, it is lifted up the curve by the reaction against the nearly vertical sides of the tread.

The value of this rail depends on the fact that the slot is so narrow that the wheels of a truck cannot sink into it, and, with the pavement just flush with the tread and flange, there is nothing to keep a wheel on it, so that, not only will there be no difficulty in pulling out of it, but horses will not be constantly reminded by an increase of traction that it is their duty to follow the line of the rail. In fact where this rail has been laid, no wagon with a tire over 1½ ins. wide has been observed by the author to follow it, though when a light wagon is once in it, the horse inclines to follow the rail. This, however, results in minimum annoyance to the railroad company, as light vehicles are nearly always prompt to leave the line of rails on the approach of a car, however difficult it may be. One other form of side-bearing rail (Fig. 10) is shown. This rail has not been laid in the City of New York, though the Commissioner of Public Works was approached by a surface railroad company that wished to lay it. It will be noticed that it is a side-bearing rail, with some of the vices of the Hewitt rail added. Undoubtedly, if its use had been permitted, it would have accomplished its object, namely, the confiscation of about 15 ft. of one of the principal lines of traffic.

Heretofore, where it has been thought necessary to use T rails in the streets of a city, for the passage of either trains or isolated freight cars, the stones have not been paved near the inner side of the rail, but a

space of 2 or 3 ins. between the rail and the stones is left, which often becomes of profound depth. Walter Katté, M. Am. Soc. C. E., Chief Engineer of the New York Central and Hudson River Railroad, devised the compound section shown in Fig. 11. This combination allows the paving blocks to have a side-bearing near their top, on the

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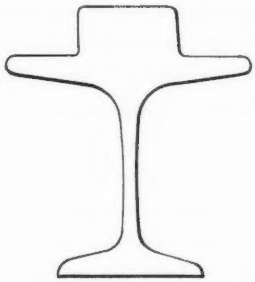

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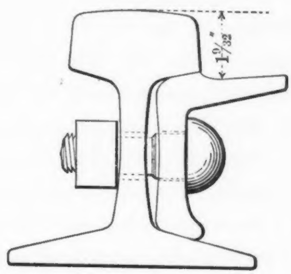

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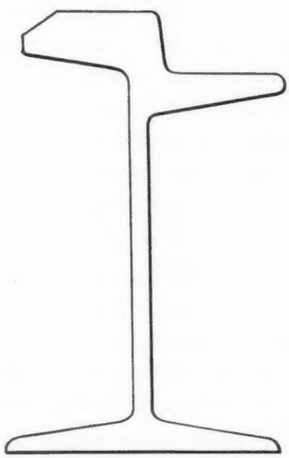

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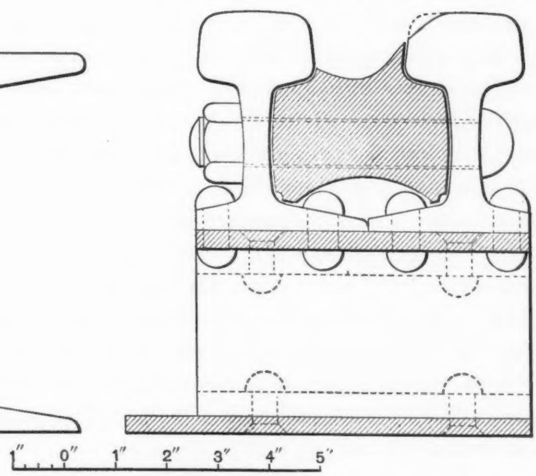

flange side of the rail, and prevents any wheel which parallels the rail dropping indefinitely between the paving blocks and the rail. The clearance for the wheel flanges, however, is unnecessarily great, as is also the depth for their accommodation, and, on the outside of the rail, the paving block can only be brought in contact with the head of

the rail by chipping off a corner, which every one knows is extremely unsatisfactory, as it is almost impossible to keep a paving block in position which has been so treated.

When the Central Railroad Company of New Jersey applied to the Commissioner of Public Works of this city for permission to cross Eleventh and Thirteenth Avenues near Fifteenth Street, with tracks leading from a car ferry landing to its yard west of Eleventh avenue, Mr. J. H. Thompson, its Engineer of Construction, presented a combination shown in Fig. 12. The rails used were the standard 60-lb. rails of the road, with a cast-iron filler between them, and a corner of the guard rail cut off; the lower flanges of these rails, as shown, are also planed off, and the combination is bolted to a wrought-iron chair. This combination, it will be observed, gives a nearly perfect side-bearing to the paving blocks, so that they can be laid without chipping, and it is hoped will keep their place rigorously. The cast-iron filler is so formed that, with the planed-off corner of the guard rail, any wheel can get out of the slot with ease. The clearance between the two rails is left as wide as it is, because a part of the track is laid on a 16° curve. This is submitted as the best combination yet offered by any railroad company for taking steam traffic through the streets of a city.

The satisfactory adjustment of the pavement to the rails presents some difficulties. Stone blocks can be solidly laid against wooden stringers, but the stringers soon rot sufficiently to let the rail down, and the joint then becomes unsatisfactory. With all girder rails of such section that both the tread and top flange are as wide, or wider, than the bottom flange, hard terra-cotta fillers moulded to the concave lines of the section and set in cement mortar give good bearings for the blocks. It is always advantageous, however, to have the height of the girder rail greater than the depth of the paving blocks. In setting these blocks the surface of the concrete should be left low, and the blocks next the rails laid in cement mortar. All ramming should be done before the initial set of the cement.

An asphalt pavement cannot be laid successfully against a wooden stringer ; in such cases toothing blocks are a necessity. With girder rails the noise from toothing blocks may be obviated by their omission. The first cost is less, but the maintenance account will be greater, as the rails so absorb and hold the heat during hot summer days that the asphalt next to them is kept soft for some time after sundown, and if the

traffic follows the rails, a crease is formed that requires repairs, which the railways are generally slow to make. When granite toothing is laid, it is better to lay alternating blocks of 6 and 12-in. lengths at right angles to the rail. Eight-inch headers and stretchers are sometimes laid, but they are not economical, except on streets of very light traffic.

In place of granite or brick toothing a steel plate about $\frac{3}{8}$ in. thick and 3 ft. wide, punched with staggered holes, has been offered. As the arrangement was patented, its specification in any contract with the city was prohibited by law. A small piece of this plate was laid in Chambers Street, where it was very satisfactory, preventing the formation of any rut.

While the section of rail adopted for most of the surface roads is obstructive to the rights and interests of the public, the style in which the space between the rails and between the tracks is maintained is often intentionally made much more obstructive. The laws of the State of New York,* make it obligatory on all surface roads to pave and keep in repair the space between the rails and tracks and 2 ft. outside of the same, but it provides no adequate penalty for non-compliance with the law. The only recourse known in the City of New York is to pave the space and charge it to the railway company, or to leave the area to the public spirit of the corporations. Eighth Avenue from Thirteenth to Fifty-ninth Street shows the result of one course ; the other method has resulted in hills aggregating decidedly over $700 000 accumulating against the surface railways on Manhattan Island from 1889 to 1895, both years inclusive.

What may be termed the Eighth Avenue method has resulted in a pavement between the rails that is seldom used by even the most stolid truckman, while the space between the tracks defies traffic of all kinds. That company has in effect sequestered a strip on Eighth Avenue over 2 miles long and about 17 ft. wide, with no other warrant than a right of way for its cars. The injury to the property on that avenue and the increased cost of transportation in the city is so great that it seems inexplicable that no grand jury should have found a bill against the perpetrators of so malicious an outrage.

On the other hand, the plan of charging the cost of an improved pavement against the company, whose income is augmented by the

* Chapter 565, Section 98, Laws of 1890, as amended by Chapter 676, Laws of 1892.

increased value and greater circulation that follows better pavements, has cost the city on an average over $100 000 per annum for the past seven years. This money has been taken from the resources of the taxpayers, but it does not follow that it has resulted in a like gain to the corporations which so persistently and successfully defy the laws of this State.

It might not be worth while to occupy the attention of the Society with this question if it was a local one, but both in cities and on country roads the surface railways, whether actuated by horse-power or electricity, devastate the highway, using an easement for a right of way on the roads and streets with a haughty disregard of the rights of others that should not be allowed if they were held in fee. In spite of the low freight rates on railroads and water-courses, this country has been injured, and, to some extent, impoverished, through the high cost of transportation on country roads, consequent upon their generally wretched condition. Concurrently with a general effort to so improve the surface of roads and streets that both transportation and circulation shall be cheaper and pleasanter, the success of these efforts are found to be threatened by the legal inability of local authorities to force owners of surface roads to maintain the area within and about their tracks in fair condition.

Some surface roads have procured charters which do not require them to maintain the pavement in and about their tracks. These claim that no additional burden can be laid on them. If this proposition is correct, it would seem to a layman that no increased rate of taxation could be levied against this property, but there seems nothing to prevent legislation which will allow municipalities and local officers in charge of roads prompt redress against corporations that now occupy the time of our courts in successful efforts to slight a duty imposed by their charters, or by general laws under which they are incorporated. Nor is there anything to prevent such legislation as will require those who are exploiting new roads, which will occupy highways, to pave, maintain and repave a much larger portion of the road or street than at present.

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CAR TRACKS AND PAVEMENTS.

By JAMES OWEN, M. Am. Soc. C. E.

TO BE PRESENTED DECEMBER 16TH, 1896.

The present enormous development of transit facilities in the streets of urban and suburban communities, and the desire for immediate results rather than for permanent construction, have already led to complications and problems which demand the careful study of the engineering profession, and to which more particular attention in the future will have to be given.

In the construction and maintenance of streets and highways, certain principles and practices have been formulated, and by selection accepted as giving the best results, economically, for the particular travel they have to endure. In the maintenance of railroad tracks, the practice has been more crystallized, and a standard has been adopted from which only the lack of means excuses a departure.

These practices exercised separately offer no field of discussion, but as soon as the maintenance of track and that of pavement are united

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in one street or in one city, then the relations of the two interests become complex, and the economic adjustment of the differences between the parties interested opens up a wide field of discussion, in what may be called, at present, at least, an undeveloped territory, and in which, therefore, it may not be considered improper to inject a few suggestions.

The first point to be considered is the relation of the owner of the railway to the authorities in charge of the highway, and involves so far three situations :

First.—Where the municipality owns both track and street.

Second.—Where the company operating the railroad assumes as part of its franchise the care of the pavement in the street.

Third.—Where the municipality cares for the pavement outside the tracks, and the company cares for the track and the pavement between the rails.

While the first two conditions actually exist, they are so rare in this country that much consideration cannot be given to them, except as to formulate what, in some minds, might be called the ideal. They have only been adopted in isolated cases, under peculiar conditions, and do not seem to commend themselves generally to municipalities or capitalists.

It will not be out of order, however, to allude to two or three ideas that suggest themselves on these two heads. It would be of undoubted advantage to have the control of track and pavement vested in one authority, as more economic results can be obtained, and the riding public and driving public would both be placed on a fairly equal basis; but the general unsatisfactory administration of municipal affairs at this time places a great barrier against municipal control. On the other hand when the railroad company assumes control of the whole pavement of the street, the company, as a money-making institution, would not have as high an idea of the character of a good pavement as the critical taxpayers would demand, and when repairs are numerous and costly, they may not be made with the alacrity that a high citizenship would suggest.

Another condition of things might exist where the municipality keeps the whole pavement in repair, and collects from the company the cost of the latter's part between the tracks. This might work satisfactorily if one point did not come up to create trouble; it is the

one point that is going to make endless friction and is the unconsidered element, viz., the repairing and renewing of the track itself.

Assuming, then, that existing condition, and for a while the future condition, is the separation of the control of the pavement from the control of the track, it will be in order to consider the relations thereto in a purely engineering sense, and from this consideration certain governing principles which may be of benefit to both parties concerned. As a basis for these relations it will be proper also to assume that the workmanship of both pavement and track are perfect, considering that any departure from this standard of perfection would only aggravate the difficulties.

The construction and operation of a horse railroad on a street or highway, while to a certain extent separating the vehicular travel from the track itself to the area left on either side or between the rails, does not by any means isolate it; and it is a matter of history that rails were especially designed to keep the wagon travel away from the car tracks, and it may be fairly assumed that the car travel was a component part of the general travel. With the introduction, however, of a higher rate of speed, either by cable or electricity, the result has been, first, to increase enormously the travel on the cars, so much so that in many cities the main car lines have practically driven away the wheel travel, and, second, the wheel travel has been forced into the two driveways and only in an emergency is the car track space used.

The result to the pavements on the streets is that the travel on them is localized into two narrow lines on which the wear is peculiarly excessive, leaving the space between the tracks rarely used. To compensate this to a certain extent is the fact that rapid surface street transit has decreased to a large extent horse travel, and also has driven a portion of the said travel on to other streets. The effect of this localization of travel on parallel lines to the track is to induce excessive wear in certain spots, and but little in others. The sequence to this, of course, is more frequent renewals in pavements, to preserve uniformity.

It is not in the scope of these remarks to allude to the merits and demerits of any particular pavement; but, to appreciate the situation properly, the accepted standard pavements now in use should be stated, and they are granite block, asphalt, brick, telford and macadam. The various cities in the country have or are making experimental de-

partures into other classes, but the list given above can be considered unchallenged. Of the pavements mentioned, the accepted practice is to lay the first three on a bed of concrete, and in many cases this concrete is continued between the tracks, and in it the ties are imbedded. In the telford and macadam streets, the spaces between the tracks are paved with block, with an edging of block outside the rails to keep the broken stone surfacing away from the rails.

Into these pavements are injected the car tracks, with, as a rule, small ties laid far apart on the bare ground, with a heavy girder rail spiked to them, and tie-rods every few feet. On track of this character loads are carried practically equal to those on steam railroads. The practice of maintenance of track on steam railroads is so matured that allusion to it here would be superfluous, but it is safe to say that every salient requirement of steam railroad track work, except the rails themselves, has been carefully ignored in street railroad track. This is due, as far as the author's observation goes, to these causes—extreme haste in the construction of the work, lack of appreciation of the future use and requirements of the road, and, probably, also to lack of funds.

This situation is, then, to be faced—a carefully laid pavement, designed with one object, particularly, viz., permanency; intermingled with it is a perishable construction requiring repairs, incessant and immediate. A prominent street railroad superintendent is credited with the statement that every street railroad track will on an average have to be renewed every ten years. While this statement may be criticized, there is good reason to believe in its accuracy.

Assuming for argument that the ten-year period is correct, the fact that every square yard of pavement within the limits of the track and also to the outer edge of the tie will have to be torn up and relaid every ten years opens up a field of speculation as to the proper practice to be adopted, both for tracks and pavement, in the future, to preserve an ideal in both cases.

Taking the case of a block pavement laid on a concrete bed, with every tie imbedded in the concrete, the actual cost of removing the material is a large item. Relaying is costly, and will sufficient care and watchfulness be given to insure a homogeneous structure afterward? Experience is apt to point otherwise. If concrete is not used between the tracks, the pavement itself will not be permanent and will

require continuous repairs to keep it up to standard, and this standard will be achieved only with great difficulty. This same argument will apply both to asphalt and brick. In the last year, more attention has been given to this question of permanency in tracks, and the use of 60-ft. rails and welded joints is to be greatly commended; but a track spiked to wooden ties laid on soft earth can never be deemed permanent, and the adoption of a track laid in concrete itself is a matter to be considered carefully. There have been for years earnest advocates of this method, and patents have been granted for such practice; but, so far, it has never commended itself strongly to that branch of the profession. It can be readily seen that rails with welded joints, firmly laid in concrete, and superimposed on this a pavement also laid in concrete, would be the desideratum, provided it can be proved that such construction of itself is inherently correct.

The substitution of steel ties for wood, laid in concrete, also suggests itself, and it would be futile to go into the region of speculation; but it is proper to insist, that a practically permanent track is to be desired, on the part of the public, for the good condition of the pavements. It must be also desired by the operating company on the score of economy; and, with a common end in view, it is natural to assume that before long both parties interested will work together.

The foregoing remarks apply to streets of cities, where there is a systematic practice of having good pavements, and with a corresponding desire to keep them so. In others, where there is indifference and even negligence on the subject, the railroad companies, as a business operation, will keep their tracks in fair condition, but the streets themselves will become practically useless for traveling.

In the relation of pavements to tracks in suburban and rural sections, the problem encountered is different in character, but none the less complex, and as the future of electric propulsion will be largely in that direction, a few ideas on that question will not be amiss.

The elimination of the idea of permanency as demanded for city work will first occur. No country highway, whether of earth, gravel, macadam or telford, is designed to give a permanent surface. The theory of use demands constant and incessant renewals in the surface, and breaking up and relaying the pavements themselves need not inflict permanent injury to them. So both track and roadway can be considered purely in their economic view.

If the present practice of wooden ties be found to be the most economical, let them be laid so, even if track surfacing be constantly necessary. The only point to be insisted on is that whatever road material is taken up should be carefully relaid and cared for afterward, to obviate settlement and unevenness.

In laying tracks on suburban and country highways, a few ideas suggest themselves which may be noted. The original tracks for horse cars were paved, as a rule, with cobble stones. Theoretically, it gave a better footing for the horses. On the substitution of electric tracks, the original cobble stones were relaid without forethought. This practice, of course, was not long tolerated, and Belgian block was substituted. It was found, however, that, except in very narrow roads, no travel ever came on the pavement except to cross it, and telford or macadam pavements were laid in the tracks, with an edging of trap rock block against the rails. Experience showed that blocks did not wear, and the macadam did. The result was that in a short time the blocks projected 1 or 2 ins. above the macadam. The later practice is now to leave out the edging and use macadam entirely. This, of course, is not applicable to steep grades, as the macadam will wash out in heavy rains from the concentration of the flow by the rails.

One serious difficulty encountered in the maintenance of macadam roads along rail tracks is the localization of travel in two parallel lines about 2 to 3 ft. from the outside rail, and it is found that the cost of repairs for the same distance is practically doubled, as telford roads originally requiring attention once in two or three years now have to be patched every year, and then with less satisfactory results.

One curious trouble found in laying the block edging against the rail on telford roads was that the sand designed to support the blocks was washed by the rains into the interstices of the foundations, letting the blocks down. Very coarse gravel and cinders used as a substitute for the sand removed the difficulty.

The concentration of travel into the parallel lines quickly caused ruts to be made, a very unusual experience to the author, and the solution of the difficulty has not yet been arrived at. Broken stone of larger size, up to 3 ins., is now being tried, and, so far, is an improvement, but the surface is rougher. This trouble, of course, only occurs when the tracks are in the center, and the driveways on the side. This brings up the question of the location of the tracks, and in

that the practice is varied. In cities as a rule the center is the only available place, and opinion is well crystallized in favor of that location; but in suburban roads the practice is varied.

On a 50-ft. roadway, a 20-ft. driveway in the center, a track on each side, and then 9 ft. for access to houses, gives good satisfaction, preserves the driveway, and lessens repairs. In a 60-ft. roadway and 14-ft. driveway outside the tracks, all the requirements are attained. In a roadway of less than 50 ft., the tracks of necessity must be in the center. Where only one track is laid on a country road, the track should be on one side, with switches towards the center.

The ideal road with trolley tracks is probably the extension of Beacon Street, Brookline, Mass. One wide roadway in the center, the trolley tracks sodded with grass, and a driveway on each side for local access give all the necessary facilities for the varying wants of the traveling public.

In the construction of Beacon Street, the company which owned the land opened the street, graded it, and was in sympathy, if not identical, with the trolley company. The result was perfection; but when a trolley company, the municipality and the property-owners are pulling in different directions, the doctrine of perfection is difficult to inculcate.

With the unexpected and enormous increase of travel on street railways due to low fares and increased speed, and a general appreciation of the profits derived therefrom, the public has gradually increased its demands upon the traction companies for the privileges conferred. The newness of the plants has so far rendered renewals unnecessary, and repairs and the cost of such repairs have not yet been fully appreciated; so, that, whether the companies will concede more to the communities, or will do less in the future, cannot be fully predicted. Until then, no permanent status of their relations can be fixed.

However, with the constant increasing demand and insistence upon good pavements and highways, the practice, both of track and street maintenance, is bound to receive the thought and consideration of professional men, and if these few remarks shall be conducive only to that end, they will not be in vain.

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PAPERS.

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THE PROPER PROFILE FOR RESISTING WAVE ACTION.*

By ROBERT FLETCHER, Assoc. Am. Soc. C. E.

ABSTRACT.

In the correspondence contributed by the author to the paper† by Theodore Cooper, M. Am. Soc. C. E., entitled "Some General Notes on Ocean Waves and Wave Force," attention was drawn to the theory of waves advanced in 1831 by Col. A. R. Émy. The most novel feature of this theory assumes the existence under certain conditions of a bottom wave caused by the oscillatory waves nearer the surface. This bottom wave is a true wave of translation, which has little or nothing of an oscillatory character, and must exert horizontal energy nearly in proportion to its mass and the square of its horizontal velocity. The present paper is a continuation of the correspondence referred to, and discusses the best profile for resisting wave action.

One of the most common modes of failure of sea walls with vertical front is the undermining of the foundations, or the wearing away and breaking up of the lower courses. Nearly every writer upon the sub-

* This paper was accepted by the Committee on Publication for filing in the Library of the Society, and will not be published in full. It is not open to discussion. It may be examined in the Library, and further information concerning its contents may be obtained by application to the Secretary.

† See *Proceedings*, April, 1896.

ject makes mention of the common failure at the foot of the works. This is often said to be caused by the "undertow," or the suction and downward motion of the water at the wall.

Rankine[14] proposes to moderate the undermining action by forming the face of the wall into steps, "so as to interrupt the vertical descent of the waters." Stevenson's experiments on a stepped wall show that on such a profile the force of the waves may be increased six times. If such construction is sufficiently massive, with joints absolutely impenetrable by water or air, it may offer an efficient check; but with the usual imperfections in such work, it would appear that the wave of translation has simply more points of attack, and that the destruction of the lower courses is likely to be rather hastened than retarded.

Émy advocated a profile which shall present no sudden obstacle to the rapidly moving bottom wave, but shall deflect it from its horizontal movement, and compel it to expend its energy in raising itself and the superincumbent weight of water. While the cycloid was proposed as specially suitable, the form is not of chief importance, provided the curve is tangent to the bottom and of a radius sufficient to promote gradual deflection of the largest bottom waves.

Émy rebuilt the sea defences of St. Jean de Luz, at the head of the Bay of Biscay, by a long incline. A former expensive breakwater there, built of concrete and stone, with an average front slope of one vertical to three horizontal, and with a footing of heavy stones confined by piles just below low-tide level, was completely destroyed, chiefly on account of this provision. These rocks, some of which weighed 4½ tons each, acted as missiles, impelled by the furious bottom waves, and made the destruction far more rapid and complete by a veritable bombardment.

The use of heavy material and steeper slopes is perhaps the most common way of opposing wave action. Rock is dumped into the sea and allowed to find its place. Admirably adapted to some localities, where large stone is plenty and where the wave energy is not great enough to move the stones, this system is generally used; but such works are often very expensive, require years of repairing before any degree of permanency is secured, and may be broken up again by the next great storm. The use of small stones in such cases invites failure. Half a century ago the Plymouth breakwater had changed its form

[14] Rankine's "Civil Engineering," p. 761.

three times, and each time its base was extended and sectional area increased. At Cherbourg the same thing had happened, and the breakwater was said to have a base 350 ft. wide.

In some reports of the Corps of Engineers, U. S. Army, the question of foundation is dismissed with the statement that anything capable of bearing the weight of the upper part will do up to within 15 ft. of low water, because there is little action below that depth. This reasoning has led to the use of small material for the lower slope and to reserving the heavy blocks for the upper slope. The facts are that on most breakwaters built of *pierres perdues* not reaching far above sea level, the material from the seaward slope is carried over to the harbor side by the waves. For example, at Plymouth stones weighing from 3 to 8 tons each, firmly fixed in the pavement of the seaward slope, were torn up and projected over the breakwater into the sound.

At Delaware, before the completion of the breakwater, a stone weighing 7 tons was moved 18 ft. from the outside to the inside of the ice-breaker, and 200 tons of heavy stones, which had been well wedged together, were swept over to the inner side.

Vertical walls have been built on large mounds of stone, to prevent the passage of material from the outside to the inside, but it is evident that they may be subjected to heavy bombardment, and are never quite safe from settlement if the loose stones of the foundation are displaced. Émy designed walls with a curved face tangent to the bottom and having sufficient radius to deflect the largest waves.

Although these walls had existed but ten years at the date of his book on waves, they had proved much more durable than the old-style walls.

Émy was not the first to propose the curved front. Franz Gerstner, of Bohemia, had recommended it previously, and, later, English engineers have decided in favor of it, and the *Proceedings* of the Institution of Civil Engineers contain many discussions as to the merits of vertical, inclined and curved profiles.

For works designed primarily for other purposes than to hold the sea in check, as sea walls, lighthouses, etc., J. Scott Russell held the concave profile to be unquestionably the best form, for it approximates to the line of least resistance. Works rising above the surface of the sea, and designed to stop the waves so as to produce comparative calm, should exert a uniform action. To accomplish this,

he says: "The cycloid is the approximate form, and especially so when the materials are weak and not abundant." If there is a profile which will enable weak materials to do the work of strong, the question may well be raised whether it is good practice to use any other form.

Mr. Russell urged objections, of which a chief one is the fact that the water is forced up higher than is the case with a vertical wall, and that the parapet is more likely to be torn off, but this distinguishing feature would seem to be an advantage, for the force which raises the water would have been expended upon the wall itself. The parapet, if built smooth with no projections, will suffer no great impact, and may be curved slightly forward so as to throw the water seaward. Another objection is that the pressure is thrown higher up the wall, but it would seem that this is preferable to lower action on vertical walls, which destroys the foundation and causes the failure of a large part of the work.

Having referred to Mr. Russell as an advocate of the cycloidal profile, it must be said that he considered it useless and injurious for certain kinds of waves which he believed to exist. He thought that the rollers which occur at the Cape of Good Hope and other places, and the common ground swells, have a forward motion *en masse*, the whole depth of water rushing forward and then receding. This agrees with the observations of Sir John Coode at the harbor of Colombo, who stated that water is forced up 120 ft. above sea level by waves which are only 15 ft. high at the moment they strike the rock. He believed that during the occurrence of the heavy monsoon swell, it was the swell itself, not a broken sea, which came in with a great roll. On the other hand, these swells in mid-ocean do not have any perceptible motion of translation, but are taken as the true type of a wave undulation.

That these immense swells really entrain very large masses of water, is likely; if so, the bottom waves may become so large as to constitute the greater part of the whole wave, and, in shallow water, operate to impart to nearly the whole mass of the entire wave an energy horizontally directed. Mr. Russell would use a long reversed curve, concave above and convex below, to resist such action. The abrupt rise at the bottom would destroy much of the momentum of the bottom wave, but it would be subject to a large share of the shock that destroys the footing of vertical walls.

At Aberdeen the pier head was first constructed as a vertical wall in shoal water, but, "the foundations being insecure," it fell more than once from the "constant percussion of the undertow." "The cycloidal form was then adopted, by which a gradual resistance was offered to the force of the waves, and the head has stood for half a century" (reported in 1860).

Concave walls have been built near Edinburgh which have had varying success, and have been pointed to as throwing doubt on the practicability of that design. Nothing can be proved conclusively by them, because they were built of very light materials, and had other defective features. Still, compared with the massive vertical walls in the neighborhood, costing many times as much, they have done good service. The south pier at Whitehaven, built with a curved face and an apron of large stones founded upon sand, has resisted many great storms. Mr. Scott Russell cited this case as gratifying to him because of its success, although only an approximation to his recommended profile.

Lighthouse builders have made use of the concave profile because of its great stability, and, although not designed primarily to deflect waves of translation, the action at Eddystone and at other lighthouses shows fine examples of the manner in which it deflects and directs the energy of the waves vertically instead of allowing them to act horizontally against the structure.

Among modern French engineers the curved profile is not held in general favor. Some four years ago the author addressed an inquiry to M. Guillemain, Director of the National School of Bridges and Roads of France. The latter quoted the following opinion of M. Laroche, Engineer in Chief:

"Experience appears to justify curved fronts in a certain number of particular cases, and for special works exposed to less violent waves which have been broken by their passage over the incline of long submarine beaches of gentle slope; also, a curved front at the summit of slopes of shifting beaches for defence.

"Per contra, practice seems to have shown that for great jetties exposed to violent seas, the curved form of exterior front does not palliate the shock of the waves, at least during the continuance of real tempests.

"In fact, during a gale, the billows do not approach a jetty under the hypothetical conditions upon which some have reasoned. It is no longer a layer of water which glides upon the slope of the sub-

structure, as does the billow which exhausts itself upon a beach of gentle slope; it is an enormous mass of water, a veritable liquid hillock, of which the ridge, mounting above the sea, precipitates itself with a crash upon the work, and strikes almost at the same instant the whole height from the parapet to the top of the substructure. Under these conditions it is conceivable that a curvature of the front, a curve always rather slight at best, can have only a small influence upon the violence of the shock of the billow.

"Indeed, jetties with a curved front require, in order to insure the stability of the parapet, a cube of masonry quite as considerable as jetties with a straight front, and the billows surmount as well the former as the latter, while the tempest lasts. So that curved fronts appear to have advantages only in tractable weather, that is to say, when one can conveniently exempt one's self from having recourse to a disposition which leads always to costly requirements in execution.

"The theory of curved fronts requires quite a sharp angle at the base of the superstructure, so that the wave may reach it without shock, and this condition had been at first observed at St. Jean de Luz; but this thin part, lacking in solidity, was repeatedly broken and destroyed. It has become necessary to commence the curve immediately above the blocks of the substructure, and to give at the base of the superstructure a vertical front of 2 m. height.

"Finally, and within the limits which permit us to formulate an opinion of by no means general application upon questions so complex, so controverted, and where, moreover, local and special circumstances play so important a part, we can state that the form of the exterior front of the superstructure of a jetty is indifferent from the point of view of the resistance of the work during tempests. It is expedient, then, in most cases to adopt the more simple and more easily realized form, namely the plane front."

M. Guillemain adds: "The opinion of M. Laroche is that of the greater number of French engineers, and all breakwaters which have been recently built in France and in Algeria, with rare exceptions, have received plane fronts rather than curved."

It appears certain, however, that the curved profile has, by actual comparative trials, proved more efficient and permanent than the plane front in some situations; and that it should be used under those conditions which are favorable to its application. For example, on rock bottom at or not far below low-water level, the tangential junction of the curved toe with the rock may be properly made, and if the lowest courses are dowelled and clamped together and the joints of the entire front made water-tight as low down as possible, a much smaller cross-section would be required because of the relief from direct impact

afforded by the deflecting curve where the waves are not too severe. Other favorable conditions and dispositions will be recognized by the experienced engineer.

It is hardly conceivable that there is any case where the body of the sea comes upon a work *en masse,* with a common horizontal velocity throughout, excepting that of the earthquake wave, which, fortunately, is not common, and which man should not expect to oppose successfully by any work which he has the means to build. This is a great sway, backward and forward, like that produced in a tub of water which is tilted. The tidal bore is not to be classed as a wave to be resisted by a breakwater.

The history of jetties and breakwaters is largely one of failures, costly and often repeated. Too much has been done in many places without a sufficient study of past experience, or an adequate idea of the enormous energy and the mode of action of storm waves. Witness on a very small scale the utterly inadequate means and methods of shore protection adopted at some seaside resorts, as Long Branch and Coney Island, where, if it is true that sufficient works would be too costly, it is no less true that there should be enough appreciation of the task to deter from such futile endeavors.

Nevertheless the judgment of the engineer must be largely guided by a knowledge of such failures, and it is to be regretted that the record of failures and damages to such works is not more complete, especially as relating to jetties and breakwaters on American coasts and lake ports.

The standard type of breakwater adopted by the Corps of Engineers, U. S. A., for the harbors of the Great Lakes is a timber crib of rectangular cross-section, filled with stone and resting usually on a broad base of random stone which the waves have compacted into a more or less stable profile. While generally doing good service for that type of construction, which is approved as usually the best within the means available for construction and maintenance, these works have not proved altogether satisfactory, having been repeatedly destroyed at certain points in various harbors. While the writer would not presume to make direct criticism of the system so long adhered to by distinguished engineers, he considers it a fair question whether the principle of the curved profile is not especially applicable in such exposures as are found on the Great Lakes. Cribwork has been and may

readily be built with a curved front and the face protected by planking below low water and as far above as desired. Such a mass is peculiarly subject to the disintegrating action of water pressure transmitted through all the interstices, and it would seem that the double-planked concave front would give such deflection to the storm wave as would greatly mitigate the shock.

Mr. W. R. Kinipple calls attention* to the great value of monolithic work of concrete for breakwaters. His experience of thirty years has convinced him that such construction, carried down even to the bed of foundation, and including all the substructure by a process of injection and "stock-ramming" of cement grout, embodies the true principle, by avoiding all the difficulties of joints, dowelling, clamping, dovetailing, and the inherent weakness of a substructure of separate fragments, where the conditions are especially suitable for destructive action of violent waves. He has successfully reconstructed and extended important works by this system, and claims greater efficiency, durability and less cost than for any form of jointed structure. It is needless to add that concrete is particularly well adapted to the execution of a curved profile.

* See *Engineering*, Vols. l and liii.

MEMOIRS OF DECEASED MEMBERS.

Note.—Memoirs will hereafter be reproduced in the Volumes of *Transactions*. Any information which will amplify the records as here printed, or correct any errors, should be forwarded to the Secretary prior to the final publication.

ECKLEY BRINTON COXE, M. Am. Soc. C. E.*

Died May 13th, 1895.

Eckley Brinton Coxe, born at Philadelphia on June 4th, 1839, came of a family long identified with American history. In the last decade of the seventeenth century, one of his ancestors, Dr. Daniel Coxe, of London, purchased a patent granted originally by Charles I and covering the territory between the 31st and 36th parallels, and from the Atlantic to the Pacific, which was exchanged by his grandchildren for 100 000 acres in New York. He also had large holdings in New Jersey, and did much to build up trade in that colony. Dr. Coxe spent most of his life in London, but his son, Col. Daniel Coxe, lived in America from 1700 until his death in 1739. He took a prominent part in local political matters, and was a Judge of the New Jersey Supreme Court. His son, William Coxe, was a merchant in Burlington, N. J. The son of William Coxe, Tench Coxe, was a well-known figure in public affairs during the early history of the United States. He held several national offices and devoted much time to encouraging the growth of cotton, and it was to his recognition of the value of the Pennsylvania coal beds that the present mercantile position of the Coxe family is largely due. He formed a partnership with some acquaintances and acquired some of this coal land. His son, Judge Charles Sidney Coxe, bent most of his energies to extending and uniting this coal property, and when he died, in 1879, the great estate was in an excellent condition, financially and legally.

Just as Judge Coxe had his life work laid out by the affairs left him by his father, so did his children find their labors were outlined by the family coal properties. Eckley B. Coxe, one of these sons, soon became prominent as their technical administrator, and his engineering knowledge and experience made him one of the foremost mining engineers of his time.

He graduated from the University of Pennsylvania in 1858, and subsequently took a post-graduate scientific course there. His early knowledge of practical engineering matters was acquired during the summers spent on the family coal lands, where he was often a member

* Memoir prepared from papers on file at the House of the Society.

of surveying parties. He thus became acquainted with the details of mining and preparing coal, and also of the topographical and geological features of the great property, so that when he began his technical studies, their practical import was apparent to him from the outset.

His progress in the European schools was excellent. At the École Nationale des Mines in Paris, where he remained for two years, he is still remembered, and his interest in that institution throughout his life was marked by many donations to it. At Freiberg he became well acquainted with Prof. Julius Weisbach, and published a translation of a portion of the latter's text-book on mechanics, which has long been recognized as an engineering classic.

In 1864, he returned to the United States. He was then twenty-five years of age and possessed of a wide theoretical knowledge of the principles of mining engineering. The great coal properties of the family estate were then worked in part under leases held by large operators, and Mr. Coxe quietly went about to acquire these leases, so that the entire output of the property would be under the control of its owners. Such a task was naturally a difficult one, but it was gradually accomplished. The Cross Creek Coal Company, of which Mr. Coxe was president, was organized to manage the mining operations. The Delaware, Susquehanna and Schuylkill Railroad Company, owned by the members of the Cross Creek Company, was organized to give the collieries of the estate an independent railway connection with the Pennsylvania, New Jersey Central, Reading and Lehigh Valley systems, so that the transportation of coal to the seaboard was not confined to a single line. A selling agency, Coxe Brothers & Company, was incorporated to market the coal, and built docks at Perth Amboy, Buffalo, Milwaukee and Chicago. The Coxe Iron Manufacturing Company was organized to carry out the construction and repair of the mining and railway machinery of the allied companies, and also took large outside contracts for machinery.

As the president of all these companies Mr. Coxe was naturally a busy man, yet he found time to give personal attention to many other matters. The welfare of his employees and their families engaged his attention to a marked degree, and insurance funds, schools and other evidences of his regard for his men have been frequently described by his biographers. It is characteristic of the man that even when labor troubles were in progress, and he was the victim of sympathetic strikes, the needy families of the men who were out found relief at his home. When Franklin B. Gowen was engaged in putting down the Molly Maguire lawlessness, Mr. Coxe was his hearty supporter and shared in his personal danger during those troublesome times.

Mr. Coxe was a Democrat in politics, but while he took an interest in public affairs, he was not personally active. He was elected a State

Senator at one time, but had conscientious scruples against taking the oath of office, and did not occupy his seat until re-elected by an overwhelming majority.

He was an ardent believer in technical education and was a Trustee of Lehigh University from its beginning. In one of his last letters he wrote to a friend that he was living for two things—this university and the utilization of small coal. As a member of the Pennsylvania State Commission on "Waste of Anthracite Coal" and of the Commission in charge of Second Geological Survey of Pennsylvania he did much work, and aided the investigations of these important commissions with a lavish expenditure of time, money and privately acquired data. In recent years, his experiments looking towards the utilization of small coal have attracted much attention, and his apparatus for preparing and burning it have been described frequently.

Mr. Coxe was elected a Member of the American Society of Civil Engineers on February 7th, 1877. He was one of the founders of the American Institute of Mining Engineers, and was actively engaged in its management during twelve of the twenty-five years of his connection with it, which terminated only at his death. He was President of the Institute in 1878 and 1879, and held the same office from 1892 to 1894 in the American Society of Mechanical Engineers. He was also a member of a large number of other scientific and social clubs in this country and abroad.

Mr. Coxe died of pneumonia on May 13th, 1895, after a short sickness, and was buried in a little churchyard within a stone's throw of his offices in Drifton. His wife, an invalid for many years, two brothers and a sister, survive him.

HOWARD SCHUYLER, M. Am. Soc. C. E.*

Died December 3d, 1883.

Howard Schuyler was born at Ithaca, N. Y., December 11th, 1844. He received a thorough academic education at the Ithaca Academy, and at the age of fourteen was preparing to enter college when the family removed to Kansas in the spring of 1859. His studies were interrupted by this removal to the frontier, although his faculty for intense concentration enabled him to cover a wide range of scientific reading under adverse circumstances, and he absorbed knowledge with unquenchable thirst and avidity. Two years of severe physical

* Memoir prepared by James D. Schuyler, M. Am. Soc. C. E.

toil and hardship preceded the outbreak of the War of the Rebellion, and in May, 1861, he enlisted as a private soldier in the 2d Kansas Regiment. He was then little more than sixteen years old, but so mature of mind and physique that he easily passed muster as a man of legal age. Under General Lyon he was in the battles of Forsyth, Dug Springs and Wilson's Creek, after which his regiment, having served the six months of its enlistment, was disbanded, and he re-enlisted in the 11th Kansas Infantry, which was attached to the army of General Blunt, then in Arkansas, and participated in the battle of Cane Hill in November, 1862, and of Prairie Grove the month after. In January, 1863, he was commissioned First Lieutenant for bravery in the field, but declined the commission because of his youth and inexperience, and in the June following he was appointed Lieutenant of Artillery for conspicuous bravery, which he also declined. Three months later he accepted the position of Captain in the 11th United States Colored Troops, and, after bringing his company to a high degree of discipline, he was transferred to 4th Arkansas Cavalry as First Lieutenant, and afterwards was promoted to the rank of Captain, which he held until the close of the war. He was then offered a commission in the regular army, but declined to accept it, preferring to practice the profession which he always had in view, and for which he had been fitting himself. In all of his army service he passed through numerous pitched battles, where the fighting was almost hand to hand, but escaped without a scratch, although his clothes were riddled by bullets.

Shortly after leaving the army he entered the service of the Kansas Pacific Railway as rodman, while the road was being constructed between Lawrence and Topeka, Kan. He won promotion rapidly, and successively became leveler, transitman, and Locating Engineer in charge of a party. In 1867 he was put in charge of one of five parties selected to survey the route of the thirty-fifth parallel road across the continent, under General William J. Palmer, and carried his line through to the Pacific Coast, completing the survey in the spring of 1869. It was an expedition requiring nerve, bravery and physical endurance in every member of the party, as they were harassed on all sides by Indians, and were subject to the hardships of thirst and starvation. On the completion of this survey he resumed charge the location of the main line of the Kansas Pacific, from Fort Wallace to Denver, about 200 miles, and completed its construction to that city in 1870. It was during this construction that he suffered the remarkable experience of having a locomotive pass over his foot, crushing all the bones of the toes, and yet recovered the complete use of the member. After his recovery he was promoted to Assistant Manager and Paymaster, which position he filled until the completion of the road to Denver.

During all these years of work on the location and construction of the Kansas Pacific Railway, the surveying parties were continually harassed by hostile Indians, and were frequently obliged to fight for their lives. His army life and acquaintance with warfare was admirable preparation for this experience, and on one memorable occasion, June 19th, 1869, Mr. Schuyler, while leading the advance of a preliminary survey near Sheridan, Kan., and while engaged in picking out a line for the party a few miles in the rear, was surprised and surrounded by a band of 100 or more hostile Cheyennes, but by coolness and presence of mind, he cut his way through the lines and escaped without a scratch, killing four Indians in the engagement. Five bullets were lodged in his horse; his field-glasses and one spur were cut off by bullets, and his clothes were well riddled; even the handle of his carbine was pierced and nearly torn from his grasp by a rifle ball. His plucky defence of himself saved the lives of the rest of the party, and they all succeeded in retreating to the military post fifteen miles distant, fighting their way through the swarming hordes of savages, whose well-laid plan for picking off the party one at a time was baffled by the coolness of their intrepid leader. The only member of the party wounded in this thrilling adventure was the writer.

In 1871 he became one of three organizers of the Denver and Rio Grande Railway, and was appointed its Secretary and Treasurer. In its service he visited Europe with General Palmer to examine the narrow-gauge railways of Wales and to interest foreign capitalists in its construction, in which they were highly successful. He afterwards filled the position of Chief Engineer and Assistant General Manager until May, 1873, when he resigned to accept the position of Chief Engineer of the North Pacific Coast Railroad, in California, and constructed the road from Sausalito, opposite San Francisco, to the Russian River, its northern terminus for many years subsequently.

In June, 1880, Mr. Schuyler was appointed Chief Engineer of the Mexican Central Railway, with headquarters at the city of Mexico, and located and constructed the road as far as the city of Leon. The strain which this work imposed upon his physical resources can only be appreciated by those who have undertaken the task of railroad construction in a foreign country, dependent upon a class of labor the most ignorant, inert and impassive on earth, with no conception of energetic completion of a task undertaken, but with innumerable feast days to be celebrated, during which all work must be suspended. Overwork and exposure in a malarious climate undermined his health and obliged him to retire and take a trip abroad in the spring of 1883. He was accompanied by his family and visited various health resorts and consulted eminent specialists, but finally succumbed to a complication of diseases at Davos, Switzerland, December 3d, 1883, leaving a wife and one son, the latter born in the city of Mexico.

Mr. Schuyler was a man distinguished among all who knew him as one of rare personal charm and magnetism, making hosts of friends wherever he went or with whomsoever he was thrown in contact. This enviable gift, combined with a natural faculty he possessed as a leader of men, and executive ability and capacity for systematic organization of an unusual order, constituted the secret of his success and gave promise for a brilliant future could he have rounded out the full measure of life. A keen sense of honor and dignity influenced all his actions and compelled his recognition as a gentleman in every sense that word implies.

ALBERT FRANKLIN NOYES, M. Am. Soc. C. E.*

Died October 12th, 1896.

Albert F. Noyes, son of George H. Noyes, was born in South Boston in 1850. The family removing to Melrose, he was educated in the public schools at that place, and prepared for his special career at the Lawrence Scientific School of Harvard University, Cambridge, Mass. From July, 1871, to November, 1873, he was an Assistant in the office of Ernest W. Bowditch, Jun. Am. Soc. C. E., and Mr. Charles H. Bateman, engaged chiefly on topographical surveying and landscape architecture. Subsequently he was Principal Assistant to Mr. Frederic Schoff, City Engineer of Newton, Mass., and from March, 1875, to February, 1876, was Acting City Engineer of that place.

He was appointed City Engineer of Newton in February, 1876, and filled that position for seventeen years. During this long term of office the development of the city constantly increased the demands made upon the office. Besides having charge of all the city surveying, making all plans for public works, the City Engineer had the laying out of all works on the highways and had to keep the accounts of all highway expenses, and was engineer of the Water Board. In 1882 he was appointed Plumbing Inspector for the Board of Health, which position he filled for several years, remodeling the plumbing regulations. In 1882–83 he was called upon by the Public Property Committee to make a sanitary survey of all the school houses, and designed and executed plans for heating and ventilating several of the old buildings. He mapped out a proposed plan for a 376-acre park in the central part of the city. He inaugurated a system of highway accounts, whereby the actual cost of each class of work was kept distinct, thus enabling him to make accurate estimates of any work proposed to be

* Memoir prepared by H. D. Woods, M. Am. Soc. C. E.

done by the Department. In 1884 he made a sanitary inspection of the city with reference to sewer requirements, and in 1887, with members of the city government, visited the separate system of sewers as constructed in various towns and cities in New Jersey and Pennsylvania, also Pullman, Ill. In 1890 he made a comprehensive report on a separate system for the city of Newton, which included 130 miles, estimated to cost $1 750 000, or an average of $2 56 per foot. The system was adopted and construction commenced the following year, over 40 miles being built under his administration. In 1889 in connection with Alphonse Fteley, M. Am. Soc. C. E., as Consulting Engineer, he made a report on the additional water supply for the city of Newton, and also on a high-service system. In 1892 the additional supply work was carried out by building a covered filtering conduit and the first covered masonry reservoir in this section of the country. In 1892 in connection with Mr. Edward Buss, he made an exhaustive report on a system of surface drainage for the whole city, which included the improvement of the various brooks, forming a series of parkways through the city. Nearly one mile of Cheese Cake Brook was straightened and deepened and laid out with drives on either side under this proposed improvement. Early in 1893 in connection with Charles A. Allen and George S. Rice, Members Am. Soc. C. E., he reported on a plan for abolishing the various crossings on the Boston and Albany Railroad through the city. Plans for several miles of boulevard 120 ft. wide were prepared the same year, but, owing to legal questions, actual work was not begun during his administration.

On July 24th, 1893, Mr. Noyes resigned his position as City Engineer of Newton to accept the position of Assistant Chief Engineer of the Massachusetts State Board of Health, to make a special study of the ground-water supplies of the State. During 1893, 1894 and 1895 he examined and reported on the water supply of forty or fifty places in Massachusetts. He also investigated the availability of the Ipswich and Shawsheen Rivers and the water-shed of the Charles River for a portion of the metropolitan supply. From 1886 to 1889 he investigated and reported on systems of ground-water supply for the cities of Malden and Brockton and the towns of Reading and Medford, and also on the distributing system for the Milford Water Company.

In 1894 he was appointed by the Governor a member of the Metropolitan Sewer Commission, to succeed Mr. Harvey N. Colligan. This was an especially appropriate appointment, as from its start Mr. Noyes had been conversant with the work and plans of the metropolitan sewer construction, and the requirements of the outlying districts, the city of Newton being one of the first to connect with the system. In 1895 he was elected to represent his ward in the Board of Aldermen of the city of Newton, and was appointed on the Highway Committee and Chairman of the Sewer Committee.

He closed his connection with the State Board of Health, and in February, 1895, formed a partnership with Allen Hazen, Assoc. M. Am. Soc. C. E., under the firm name of Noyes & Hazen, making a specialty of sewer and water-works investigations and construction. In the line of water supply this firm made investigations, surveys or reports for Austin, Tex.; Far Rockaway, L. I.; Menominee, Mich.; Columbus, Cleveland and Painesville, O.; Harrisburg and Du Bois, Pa.; Jersey City, N. J.; Ashland, Wis.; Indianapolis and Princeton, Ind.; Greenfield, Munson, Lynn and Adams, Mass.; and for a high service supply for Lawrence, Mass., and Hartford, N. Y. In the line of sewerage it was connected with the design or construction of sewer systems in Altoona, Pa.; Plainfield, N. J.; Vassar College, Poughkeepsie, N. Y.; Spencer, Quincy and Melrose, Mass.

Mr. Noyes showed remarkable ability and excellent judgment. He was a broad-minded public official, and a very careful, conscientious worker, adhering strictly to the course which he considered best for the city. He was a constant student, and never undertook any work without examining the subject from all sides, and ascertaining how to obtain the best results with the least expenditure of public funds. As an example of this, when the work was commenced on the Newton sewer construction, and the various pipe dealers had made a combination and fixed prices, he visited, with the Chairman of the Sewer Committee, the principal pipe yards in the Akron and Ohio River districts, St. Louis and the Potomac Valley, to ascertain the ability of the yards to furnish the material required, and to get information which would allow him to better judge the quality of the pipe required. He was able in this way to make contracts with firms outside the combination, and to get some of the best pipe that was ever used in an eastern market at a considerable saving to the city. Whatever matters were brought to his attention were thoroughly investigated, and whatever knowledge was required outside of his own experience was carefully looked up, and the advice of the best authorities sought before settling on a definite policy.

He was generous and kind, had a pleasant greeting for everyone, and would listen patiently and attentively to all grievances brought to his attention, endeavoring to give everyone justice, and to repair all apparent wrongs which might be caused to private individuals through the carrying out of public works. By his death the city of Newton lost a valuable public-spirited official and citizen, who was ever mindful of the welfare and development of the city. The State lost a valuable adviser, and the engineering profession one of its most prominent members, he being considered one of the foremost engineers in his specialty. He was regarded as an expert in matters of ground-water supply and sewerage, his advice being sought from various parts of the United States.

Mr. Noyes was elected a member of the American Society of Civil Engineers on December 3d, 1884. He was a Member and Past-President of the Boston Society of Civil Engineers, and at the time of his death was Vice-President of the Massachusetts Highway Association. He was President of the New England Water-Works Association for the years 1890 and 1891. He leaves a widow, one son and two daughters.

WILLIAM HARRISON GRANT, M. Am. Soc. C. E.*

DIED OCTOBER 12TH, 1896.

William Harrison Grant died at his home in Sing Sing, N. Y., Saturday, October 12th, 1896, aged eighty-one years and five months, having been born May 15th, 1815. He was descended from William Grant, a revolutionary soldier who was pensioned for his services in both the army and the navy.

When nineteen years old, Mr. Grant entered the New Paltz Academy, where he studied mathematics and surveying. He began practice in country surveying and on the New York and Erie Railroad, after which he went to Ithaca Academy to continue his mathematical studies and complete his education. Soon after leaving the academy he was appointed Assistant Engineer on the enlargement of the Erie Canal under William J. McAlpine, where he remained some eight or nine years. During intervals in his canal service, he spent two winters in the Legislature at Albany as Deputy Clerk, and also acted as assistant to Adjutant General Niven. Later he was employed as Assistant Engineer on the Hudson River Railroad survey under John B. Jervis, and before that road was completed, he was appointed Chief Engineer of the Cleveland, Zanesville and Cincinnati Railroad, of which he constructed 60 miles. He was then called to Washington, D. C., and took charge of a railroad survey from Georgetown to Hagerstown, Md. This road was not built at the time, but the surveyed route was afterwards occupied by the Baltimore and Ohio Railroad.

Returning to New York, he was appointed Superintending Engineer of Central Park, and was connected with the work until its completion. In later years, he looked back upon this portion of his professional career with the greatest pride. Following his connection with Central Park, he was appointed Superintending Engineer of the Department of Public Works of New York City, his charge embracing the annexed district, across the Harlem River, now the 23d and 24th Wards of the city. He afterwards became Constructing Engineer of the Department

* Memoir prepared by Alfred P. Boller, M. Am. Soc. C. E.

of Public Parks. In 1876 Mr. Grant formed a partnership with Donald G. Mitchell, as landscape architects, but in a year or two he accepted an appointment from the general government on the improvement of rivers and harbors in Maryland and Virginia.

Mr. Grant had a large and varied experience in engineering work, and in addition to the engagements already noted, there were terms of service upon the Eastern Division of the Ontario and Western Railroad, and the northern half of the West Shore Railway. He also furnished the plans and constructed in part the Yonkers system of water works. His last public place was as Superintendent of the new United States Naval Observatory, Mr. Richard M. Hunt, architect. On the near completion of the several buildings under his charge, he resigned his position, retiring in 1893 from the active practice of his profession, and passing the remainder of his life at Sing Sing, N. Y.

Mr. Grant was one of the early members of the American Society of Civil Engineers, which he joined on July 2d, 1873. In early life he married Miss Mary Locke, of Sing Sing, daughter of James Locke, and sister of Rev. Dr. Clinton Locke, of Grace Episcopal Church, Chicago. She survives him, together with three children: Dr. Frank S. Grant, of New York City; Mrs. James E. Childs, wife of the General Manager of the Ontario and Western Railway, and Miss Teresa Grant. Mr. Grant was one of the very last of the old-school engineers, with whom engineering was wholly a development from subordinate field positions. In their youth the technical school was unknown, and there was no engineering literature to draw upon. They were bold and resourceful men, who accomplished much in their day and generation, and paved the way well for the great later-day triumphs of the profession.

The probity of character that attached to these men was highly marked in Mr. Grant, whose uncompromising integrity was one of his strongest characteristics, although coupled to a most kindly disposition.

THOMAS PROSSER, M. Am. Soc. C. E.*

Died September 15th, 1870.

Thomas Prosser was educated in England as a civil and mechanical engineer and architect, and practiced his profession for some time previous to his removal to the United States, which took place about 35 years ago. In this country he has been better known as a mechanical engineer and inventor, and was for several years engaged in the manufacture of boiler tubes.

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* Memoir prepared by Messrs. Jacob M. Clark, John F. Ward and A. W. Craven, in 1870, but never published.

An acquaintance which he formed with the proprietor of Krupp's celebrated steel works at Essen, Prussia, while visiting the London Exhibition of 1851, resulted in the appointment of Mr. Prosser to the American agency of those works, which he held until his decease. For several years past Mr. Prosser was the only agent remaining in position from among those who had received appointment by the personal selection of Mr. Krupp.

In the autumn of his life Mr. Prosser became a member of the American Society of Civil Engineers and Architects soon after its re-organization in 1867, his name being the tenth in order on the roll of new members.

He brought into our circle a thoughtful, inventive and methodical mind, well stored with useful knowledge, and, disciplined by long experience and culture, soon took a prominent place, and was during his entire membership thoroughly identified with the growth and welfare of the Society. His name is connected with many of the important business committees which have been formed, and for nearly a year preceding his decease he was a member of the Board of Direction. His duties were always assumed without ostentation, and most faithfully and punctually discharged. The minutes show that no living member has been for the same period a more constant attendant on our meetings, and his colleagues in committees and on the Board remember that his place was never vacant unless when he was detained by infirmity, and that he always came thoroughly prepared for business. His sincere convictions and thorough discipline made him a tenacious, though always courteous and manly, opponent, and as an ally, staunch and reliable.

The published *Transactions* of the Society are enriched by an interesting article from his pen, illustrating a highly ingenious method and apparatus of his invention for the conservation of heat in distillation.

Few members have bestowed a more liberal share of honest and earnest effort upon the business of the Society than Mr. Prosser.

With less of evil to "live after him" than can be said of most men, his spotless record may well be our just pride, so that the good may not be "buried with his bones."

This Committee recommends the following preamble and resolutions:

Whereas, The American Society of Civil Engineers and Architects, by decree of that Divine Power whose mandates all must obey at the appointed time, has been deprived of a valued and honored member and officer, skilful and distinguished in his calling, able and intrepid in counsel, a genial and sympathizing friend, worthy in all the relations of life; therefore

Resolved, That we tender to the surviving family and friends of the late Thomas Prosser our cordial sympathy and condolence.

JAMES BARNES, M. Am. Soc. C. E.*

Died February 12th, 1869.

General James Barnes, a prominent engineer and railroad contractor before the Civil War, and the forty-fourth Member of the American Society of Civil Engineers, was a native of Massachusetts. He was graduated in 1829 from the United States Military Academy at West Point, ranking five in a class that included, among others, Robert E. Lee and Joseph E. Johnston, against whom he was destined to carry out later those principles of warfare which they studied as classmates. After graduation he was appointed to the artillery branch, and served for about a year at the Academy as an Assistant Teacher. From 1830 to 1833 he was on duty at Fort McHenry, Md.; Charleston, S. C., and Fort Monroe, Va. Then he served as an Assistant Instructor of Infantry Tactics at West Point until August, 1836, when he resigned to enter upon a prosperous career as engineer and contractor.

From 1836 to 1842 he was Assistant Engineer of the Western Railroad, extending from Worcester, Mass., to Albany, N. Y., and now a part of the Boston and Albany Railroad, and from 1842 to 1848 he was its Chief Engineer and Superintendent. Then he went south, and from 1842 to 1848 was Chief Engineer and Superintendent of the Seaboard and Roanoke Railroad from Norfolk, Va., to Weldon, N. C. It was during this time that he became interested in contracting as a member of the firm of Phelps, Mattoon and Barnes, of Springfield, Mass., builders of the Watertown and Rome Railroad. This was a very successful contract, and led to his engaging in this business for a number of years, during which he built the Sackett's Harbor and Ellisburg Railroad, part of the Buffalo, Corning and New York Railroad, the Terre Haute, Alton and St. Louis Railroad and the Potsdam and Watertown Railroad.

On the outbreak of the Civil War, General Barnes at once volunteered, and became Colonel of the 18th Massachusetts Infantry in July, 1861. He served with distinction in the operations of the Army of the Potomac, and was in command of a division at the battle of Gettysburg, in which he was wounded. During the latter part of 1863 he was in command of the defences of Norfolk and Portsmouth, Va., and then spent six months on court martial duty. He was in command of the military prison at Point Lookout, Md., and of the St. Mary's District until the middle of 1865, when he was placed on waiting orders. On March 13th, 1865, he was brevetted Major-General of

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* Memoir prepared from an article in the "Biographical Register of the Graduates of the U. S. Military Academy," by Gen. G. W. Cullom.

Volunteers for meritorious services during the Rebellion, and on January 15th, 1866, he was mustered out of service.

In 1868 he was a member of a special United States Commission to examine and report on the road and telegraph line of the Union Pacific Railroad Company.

General Barnes died at Springfield, Mass., February 12th, 1869, at the age of sixty-three years. He was elected a Member of the American Society of Civil Engineers March 13th, 1853.

ROBERT G. HATFIELD, M. Am. Soc. C. E.*

DIED FEBRUARY 15TH, 1879.

Robert G. Hatfield, born at Elizabeth, N. J., in 1815, began his career as a carpenter and builder. He was of a studious nature, and soon fitted himself to be an architect. He designed a number of structures, chiefly warehouses and shops, but achieved his reputation as an architectural engineer. His designs for complete buildings have been criticized as not highly artistic in character, but sometimes very ingeniously planned and always well executed. In the technicalities of his profession, however, he was regarded as a recognized authority, and as his spare time for some years was spent in making experiments on the strength of building materials with a testing machine of his own invention, he acquired a large amount of data on this subject. He was a painstaking investigator of matters relating to the computation of stresses, and among his books is one on "The Theory of Transverse Strains and its Application in the Construction of Buildings." In this book are a large number of original tables based on the results of his investigations. An account of some of his experiments with stones of various classes is given in a paper presented by him to this Society at its fourth annual convention and printed in the second volume of *Transactions* under the title of "Experimental Tests of Building Stones." Among his earlier books was one entitled "The American House Carpenter," which had a considerable sale fifty years ago.

As a designer of structural work, Mr. Hatfield was frequently consulted by other architects, his best known work probably being the arched roof of the Grand Central Station at New York City. He was also frequently retained as a referee in disputed subjects, and was employed by Andrew H. Green, when Comptroller of New York, to estimate the value of the work actually done on the County Court House in that city by the contractors in the Tweed ring.

* Memoir prepared from papers on file at the House of the Society.

Mr. Hatfield was elected a Member of the American Society of Civil Engineers on December 4th, 1867. He was one of the earliest members of the American Institute of Architects and an earnest worker in advancing its growth and influence. He gave up much time to its affairs, acting as Treasurer for many years and serving as President of the New York chapter for some time. Among his papers presented to that body were two advocating improvements in construction tending to diminish danger from fires, a subject to which he paid much attention.

Mr. Hatfield died in Brooklyn on February 15th, 1879.

ADDISON CONNOR, M. Am. Soc. C. E.*

Died January 4th, 1891.

Addison Connor was born in New York City on April 2d, 1847. He was a graduate of Tufts College and of the Massachusetts Institute of Technology, and later in his life was given the degree of M. A. by the former institution. From 1871 to 1873 he served as assistant in the office of a Boston engineer, and then became transitman on the works for an additional water supply for the city of Boston. This position he held for seven years, when he became an assistant to Clemens Herschel, M. Am. Soc. C. E., and was engaged on surveys and tests of hydraulic machinery in the neighborhood of Holyoke, Mass.

In 1881, he became Resident and Assistant Engineer on the Northern Pacific Railroad, and built the company's dock at Superior, Wis., a structure 1 000 ft. long and 166 ft. wide. He was then transferred to the Missoula Division in Western Montana, and afterwards to the Cascade Division. When work on this railroad was suddenly suspended in 1884, he came east and entered the Department of Public Works of New York City as Assistant Engineer. Two years later he left this position to go to Plattsmouth, Neb., where he was employed by George S. Morison, M. Am. Soc. C. E., on surveys of the Missouri River at that place. He spent about seven months in 1886 and 1887 at Nebraska City, being engaged on preliminary surveys for the rectification of the river and the location of the bridge subsequently built there. He left Nebraska City early in June, 1877, to become one of the assistant engineers on the Cairo Bridge. Shortly before the completion of this bridge he was transferred to St. Louis, where he was engaged on some city work in connection with the new line of the St.

* Memoir prepared from information furnished by George S. Morison, A. Fteley and Fred. Brooks, Members Am. Soc. C. E., and from papers on file at the House of the Society.

Louis, Keokuk and Northwestern Railroad into that city. On the completion of his work there, he left Mr. Morison's employ, and in 1890 was appointed Assistant Engineer in the Department of Docks of New York City, where he remained until his death, which occurred January 4th, 1891.

Fidelity to duty was one of Mr. Connor's conspicuous traits. Modest and unassuming, although well equipped in his profession, the uniform reliability of his engineering work in various branches had gained for him the implicit confidence of those who employed him and who will remember kindly his able and conscientious collaboration.

Mr. Connor was elected a Member of the American Society of Civil Engineers on January 5th, 1887. He was married in 1876 to Mary E. Childs, of Framingham, Mass., who survived him.

HORACE LAFAYETTE EATON, M. Am. Soc. C. E.*

Died November 23d, 1895.

Horace LaFayette Eaton was born in Boston, Mass., on September 6th, 1851. In 1869 he entered the office of the City Engineer of Boston as rodman, and subsequently became transitman, leveler and Assistant Engineer. He was employed at one time or another on all branches of work done under the direction of the City Engineer, both in the field and in the office, so that when he was elected in 1887 to the position of City Engineer of Somerville, he was well qualified for his duties.

Mr. Eaton had the reputation of being a very careful and cautious engineer and a man of strict integrity. All of his plans were worked out with a thorough regard for every detail. In the execution of all the public work constructed under his supervision he required honesty and faithfulness, and no work which was not up to the standard was accepted. False stories were ingeniously circulated by Mr. Eaton's enemies, and were used by certain cheap politicians who wished to control the office for their own purposes, and finally the City Council was induced to order an investigation into the affairs of the City Engineer's office.

The first hearing had been held, and his enemies had told their stories, all of which were printed in a sensational manner by the newspapers, before he had an opportunity to make any defence. Mr. Eaton, already overworked, was harassed and despondent. The false

* Memoir prepared by Desmond FitzGerald, M. Am. Soc. C. E.

statements made in public so worked on his sensitive nature that, in a fit of temporary insanity, he took his own life.

The act came as a terrible shock to the community. The people of Somerville were sad and indignant, and requested the City Council to continue the investigation. It was carried on after his death in a most searching manner, the result being that Mr. Eaton was completely exonerated from every charge, and those making the false accusations were denounced for having brought them against an innocent man without any facts on which to base them.

Mr. Eaton was elected a Member of the American Society of Civil Engineers on February 1st, 1893. He left a wife and two children.

ARTHUR MACY, M. Am. Soc. C. E.*

DIED APRIL 14TH, 1891.

Arthur Macy was about twenty-five years of age when he became a Junior of the American Society of Civil Engineers in 1877. He was a graduate of the School of Mines of Columbia College, in the class of 1875, and was subsequently an Assistant in the Department of Assaying in that institution for about two years. During the spring and summer of 1876, he varied this work for a short time by acting as Engineer in charge of certain harbor improvements at Sodus Point, N. Y., which were being made by the Ontario Southern Railroad Company. For a short time in 1877 he was Night Superintendent of the works of the Pennsylvania Lead Company at Mansfield Valley, Pa., but was compelled to resign this position on account of poor health.

After a few months spent in rest and mechanical experimenting, he became Superintendent of the Kings Mountain Mining Company of North Carolina. There he remained for about a year and a half, sinking new works, rebuilding mills, and mining and milling ore. Then he went to Colorado and became Superintendent of the Pride of the West Consolidated Mining Company and of the Silver Mountain Mining Company. In the spring and summer of 1882 he designed and built the works of the Martha Rose Smelting and Mining Company, of which he was Manager until ill health compelled him to take another rest.

In the fall of 1883 he became superintendent of the Silver King Mining Company at Silver King, Pinal County, Ariz., where he made many improvements in the mining plant.

Mr. Macy was elected a Junior of the American Society of Civil Engineers on July 12th, 1877, and a Member on December 2d, 1885.

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* Memoir prepared from papers on file at the House of the Society.

ALBERT JACOB STAHLBERG, Jun. Am. Soc. C. E.*

DIED AUGUST 19TH, 1887.

Albert Jacob Stahlberg was born in Denmark in 1846. He was graduated in 1868 from the Polytechnic Institute (*Landbohöiskolen*) in Copenhagen as a "Forest Officer," and served in Sweden in 1868 and 1869 as Assistant on the work of regulating about 5 000 acres of woodland, which included the surveying and valuation of the property and the improvement of the streams running through it.

Late in 1869 he came to this country, and soon found employment as Assistant to Mr. George Beckwith, at that time the City Engineer of Bridgeport, Conn. In the summer of 1870, he entered the office of Messrs. Welton and Bonnett, of Waterbury, Conn., and under their direction was employed on the construction of water-works, railways and city works of various kinds. He remained in this office a number of years and then went to the Pacific Coast. For a time he was Assistant City Engineer of Los Angeles, Cal., and afterwards was connected at different times with the South Pacific Coast Railroad, the Oregonian Pacific Railway, and the Oregon and California Railroad.

In 1885 he visited Copenhagen on account of failing health, and remained in Denmark until his death on August 19th, 1887.

Mr. Stahlberg was elected a Junior of the American Society of Civil Engineers on March 4th, 1874.

HENRY FARNAM, F. Am. Soc. C. E.†

DIED OCTOBER 4TH, 1883.

The career of Henry Farnam, prominent as an engineer, contractor and railroad president during the building up of the Central States, is remarkable for the fact that for nearly thirty years his work was of a routine nature, and for most of the time connected with a more or less financially unsuccessful undertaking. This long period of apprenticeship, if it may be called such, brought its fruits, however, in thirteen years of unusually successful operations on a great scale, yielding pecuniary returns commensurate with their importance, and

* Memoir prepared from papers on file at the House of the Society.

† Memoir prepared from a biography written by Henry W. Farnam, Esq.

enabling Mr. Farnam to spend the last twenty years of his life in a retirement marked by many gracious acts.

He came of a Connecticut family that settled in Scipio, Cayuga County, N. Y., late in the last century. The country was then practically a wilderness, and the settlers were pioneers in many respects. Henry Farnam was born November 9th, 1803, and soon displayed an unusual fondness for books and a lack of interest in farm work. For a short time he lived with a relative, a physician, to learn if he had a taste for the medical profession, but it was soon found that this was not the case. His favorite studies were mathematical. With meager instruction and few text-books, he mastered the elements of trigonometry and surveying before he was sixteen.

In 1821, he at last found an opening that might lead to something to his taste. The Erie Canal was then under construction, one section of which was in charge of David Thomas, to whom the young man applied for a position on a surveying party. The only place then vacant happened to be that of camp cook, which Mr. Farnam at once accepted, so as to be on hand when vacancies in the surveying staff might occur. He soon rose to be Assistant Engineer, and was connected with the canal until the fall of 1824, spending the winter months teaching school. It was during this engagement that he contracted a malarial disease that for some time threatened his life. This was finally cured, however, and was practically the only sickness he had until his last few years.

From 1825 until 1850 Mr. Farnam was connected with the canal running from New Haven to Westfield. This work was undertaken in 1822 by the Farmington Canal Company, but actual construction was not begun until three years later. Davis Hurd was Chief Engineer of the company, and he offered the position of Assistant to his relative, Mr. Farnam. It was at once accepted, and in 1827, on the retirement of Mr. Hurd, was followed by promotion to the position of Chief Engineer. The canal was part of the system of waterways eventually extended from New Haven to Northampton, and controlled by the New Haven and Northampton Canal Company. It was largely built and managed by Mr. Farnam as Chief Engineer and Superintendent, whose experience in this work must have been an anxious one. The balance sheet always showed losses, which were attributed, like those of other New England canals, by its chief financial backer, Joseph E. Sheffield, to two facts—that little passenger travel could be secured, and that the canal never carried on transportation itself, but simply collected tolls, requiring a much larger volume of business to pay dividends than would be needed by a railroad.

By 1845 the company's stockholders were convinced that the canal could not be made to pay, and Mr. Farnam proposed to build a railroad along its line, abandoning the waterway. Mr. Sheffield, then

actively engaged in organizing the New York and New Haven Railroad Company, took up the idea, and with his co-operation the railroad was built, reaching Plainville in 1848, and Tariffville and Collinsville in 1850. The New Haven and Hartford Railroad was then in operation. The competition between the two lines was strong, and various deals were made between the roads, which were disappointing to both Mr. Sheffield and his chief engineer. Both withdrew entirely from eastern railroading, but that Mr. Farnam's relations with the New Haven and Northampton Company remained harmonious to their termination is evinced by the following extract from a resolution passed at a meeting of the stockholders in 1850:

"For the uniform fidelity with which Mr. Farnam has performed all the duties devolving upon him; for the unimpeachable integrity with which the many thousand dollars that have passed through his hands have been expended; for the unshaken confidence with which he carried forward these works under very great difficulties; and for the heavy personal responsibility which he often assumed to maintain the works, when otherwise they would have been sacrified, this Company entertain the highest consideration."

Although these twenty-five years were full of arduous works, of long patrols in his buggy along the line of the canal in all sorts of weather, and were rewarded with but a small salary, yet they had one important result, the formation of enduring friendships with men of great business influence and sagacity, particularly James Hillhouse and Mr. Sheffield, and it was in partnership with the latter that Mr. Farnam made his first noteworthy success as a contractor.

In 1850 Chicago was a place of 30 000 inhabitants, built in a straggling fashion on the swamp about the mouth of the nearly stagnant stream known as the Chicago River. Its facilities as a terminus for steamboat navigation were admirable, but otherwise it possessed few attractions. Two years before, the Illinois and Michigan Canal had finally been completed from Chicago to La Salle, thus connecting Lake Michigan with the Mississippi Valley. The Michigan Southern Railroad had then reached Hillsdale, 167 miles from Chicago, and a section of the Galena and Chicago Union Railroad ran from Chicago to Elgin. William B. Ogden was then President of the latter road, and at his invitation Mr. Farnam went west, with a view to becoming interested in that undertaking. The possibilities of the country impressed him so favorably, however, that he did not care to commit himself to any one project at that time.

He made another visit a little later in company with Mr. Sheffield, and in their journey through the country were much attracted by the future for a paper railroad between Rock Island and La Salle. When the road was chartered in 1847, its projectors believed that it could not compete with the canal from Chicago to La Salle, but would stand a good chance of securing a profitable traffic from the latter city west-

ward, in competition with the natural waterways. The experience in Connecticut showed, however, that such a project was not the right one, but the firm of Sheffield and Farnam offered to build the road if the charter could be amended to give the right to run through to Chicago.

Before this contract was completed, however, the new firm was given an opportunity to show its capabilities. The Michigan Southern road then stopped at Hillsdale, on account of financial weakness. John B. Jervis was Chief Engineer of the company, and he wanted Mr. Farnam to become Superintendent of the completed part of the line. The latter declined the proffered position, but agreed that his firm would build the road into Chicago, a daring offer in those days. The contract was made, and in March, 1852, the first train from the East entered Chicago over this line. Shortly afterward the Michigan Central built through to the city, which, under the stimulus of these new facilities for transportation, soon began to develop marvelously.

The legislative preliminaries in the Rock Island and La Salle project were meanwhile carried on under the general supervision of the firm. In 1851, the new charter was obtained and the name of the corporation altered to the Chicago and Rock Island Railroad Company, and soon after John B. Jervis was chosen President, and William Jervis Chief Engineer. The surveys were completed in August, and the next month the formal contract with Sheffield and Farnam was closed for building and equipping the entire road, about half the payment to be made in 7 per cent. bonds. Late in February, 1854, the first train ran from Chicago to Rock Island, and in July the road was formally turned over to the company, eighteen months before the time specified in the contract. The firm also built during this time, in company with several other parties, the Peoria and Bureau Valley Railroad, a branch of the Rock Island system. The completion of these contracts was celebrated as an event of national importance. Sheffield and Farnam took a party of over a thousand from Chicago to Rock Island, up the Mississippi to Fort Snelling, and back to Chicago. Six days were spent on the excursion, and among the guests were President Fillmore, George Bancroft, Governor Baldwin of Connecticut, Thurlow Weed, Epes Sargent, Charles A. Dana and Samuel Bowles.

Before the completion of the Chicago and Rock Island line, Mr. Farnam had investigated the opportunities for railroads in Iowa, and was convinced that they offered many openings for profitable undertakings. The first thing to be done, however, was to cross the Mississippi, and the Rock Island Bridge Company was formed to do this. The bridge built, the first over the river, was a wooden structure and aroused great opposition. Boats collided with the piers and their owners brought suits for damages, and it was once set on fire. Then the United States Government sued out an injunction against it, but

finally the company triumphed over all obstacles and a railroad connection across the river was assured.

The Iowa road was chartered as the Mississippi and Missouri Railroad, and formed part of a single system of which the Rock Island Bridge and Chicago and Rock Island Railroad were the other links. Mr. Sheffield retired from business about this time, and the firm of Farnam and Durant was formed with Dr. Thomas C. Durant. In May, 1855, a contract was taken by the firm for the construction of a road from Davenport to Iowa City, with a branch to Muscatine. A period of commercial depression came on about this time, and during the crisis of 1857, the firm came dangerously near ruin. This was finally avoided, and the road extended to Grinnell, 120 miles from Davenport. During this time Mr. Farnam was acting as President of the Chicago and Rock Island Railroad Company and of a bank, and was also actively engaged in promoting the project of a railway to the Pacific Coast. He finally became one of the incorporators of the Union Pacific Company, but soon found himself out of sympathy with the proposed methods of conducting the enterprise and ceased to have anything to do with it. He continued, however, to take part in railway affairs until June 4, 1863, when he resigned the presidency of the Rock Island Railroad Company, and retired from active work.

Five years of subsequent life were spent in travel and the remainder at his home in New Haven. He was too advanced in years to offer his personal services to the country during the Civil War, but he contributed financial support, and, with his wife, cared for wounded and sick soldiers in Chicago. He made many gifts to Yale College, gave the city of New Haven one of its most beautiful drives, and in many ways used his large wealth for the advantage of others.

His death occurred on October 4th, 1883, and was due to a stroke of paralysis. Mr. Farnam was elected a Fellow of the American Society of Civil Engineers on November 14th, 1872.

WILLIAM HOWLAND ASPINWALL, F. Am. Soc. C. E.

Died January 18th, 1875.

William Howland Aspinwall, the founder of the Panama Railroad and Pacific Mail Steamship Companies, was the grandson of Captain John Aspinwall, one of the most prominent shipmasters of the New York merchant marine before the Revolution, and the son of John Aspinwall, a well-known merchant of that city in the early part of this century. He was born in New York on December 16th, 1807, and was

educated in local private schools. At an early age he became a clerk in the mercantile house of G. G. & S. S. Howland, his uncles, and advanced so rapidly that in 1832 he was taken into partnership. About five years later Gardner and Samuel Howland withdrew from the active management of the affairs of the house, and its name was changed to Howland & Aspinwall. The business was very extensive, particularly with countries on the Pacific and Mediterranean coasts, the East and West Indies, and England, and the firm owned at one time over fifteen ships, including several Liverpool packets.

It was this wide range of business relations that led Mr. Aspinwall to appreciate the importance of the Panama route. California had just been annexed to the United States, and he believed that better means of communication across the Isthmus of Darien would prove profitable to those furnishing it, as well as a great aid in developing American commerce. Congress had sold contracts for carrying mail by steamers from Chagres to New York and New Orleans, and from Panama to San Francisco, but the persons who obtained them were unable to carry out their provisions. Finally George Law, the New York street railway builder, bought the Atlantic line, and Mr. Aspinwall obtained control of that on the Pacific. The former was then considered a good investment, but Mr. Aspinwall's commercial acquaintances regarded his purchase as a very poor bargain. It was merely part of a great undertaking, however, which developed under his management into a very profitable business, of great importance to commercial interests. In 1848 the Pacific Mail Steamship Company was chartered in New York State to carry out the mail steamer contracts, and Mr. Aspinwall remained its president until his retirement from active business in 1856.

This company carried out but half his plans, however, for he recognized, as soon as the rush for California began, after the discovery of gold on the Pacific Coast, that some method of solving the problem of rapid transit across the Isthmus, given up as hopeless by early English and French investigators, must be devised. His idea was to build a railroad across the narrow ridge of land. He found in John L. Stevens an associate familiar with the country who was willing to make an exploration of the route in company with an engineer. The result of this investigation showed that such a line could be built, and Messrs. Aspinwall, Stevens and Henry Chauncey made a contract with the authorities of New Grenada to build a railroad. The Panama Railroad Company was incorporated under the laws of the State of New York to take over these obligations, and Mr. Stevens was elected president. A contract was made with George M. Totten and John C. Trautwine for the construction of the line, and work was begun in May, 1850. It progressed slowly on account of the great natural difficulties of topography and climate, but was finally opened early in

1855. Its Atlantic terminus on Navy Bay was an uninhabited spot at the time the railroad was projected, and was for some time overshadowed in size and commercial importance by the neighboring town of Chagres. As the railroad progressed, however, it became an important place and was named Aspinwall, after the man whose enterprise had developed that region. This name was employed by English-speaking people until a few years ago, when the Colombian authorities refused to transmit mail matter to it unless addressed Colon, the Spanish name of the place. In the first seven years of operation of the road, the net earnings were nearly $6 000 000, a good proof of its founder's business sagacity. As a mark of appreciation of the work of the three projectors of the line, Messrs. Aspinwall, Stevens and Chauncey, the directors of the company erected, a few years before Mr. Aspinwall's death, a large monument at Colon, on the base of which their busts were carved. This monument stands on the beach in front of the company's property, and is one of the prominent features of the town.

After these great companies were placed on a thoroughly sound basis Mr. Aspinwall practically retired from business. Much of his time was spent in travel, and he took particular pleasure in collecting pictures and in improving his country estate near Tarrytown.

Mr. Aspinwall was elected a Fellow of the American Society of Civil Engineers on July 9th, 1870. He died on January 18th, 1875.

ALFRED KRUPP, F. Am. Soc. C. E.*

DIED. JULY 14TH, 1896.

Alfred Krupp's career as an iron master was laid out for him by his father, but the success he achieved was solely his own, and the reward of unremitting labor and bold business enterprise. His father, Friedrich Krupp, was for many years among the most prosperous residents of Essen on the Ruhr, then a little town of about 4 000 people. His great purpose had been to learn the art of making cast steel, which was practiced in England as early as the middle of the last century. During the Napoleonic wars it was difficult in Germany to secure enough of this metal to meet the demands of the manufacturers of fine tools, and many Germans tried to learn the secret. Friedrich Krupp struggled along for years and finally found it. He made steel of good quality, and in an official Prussian report of 1822, it is stated that his product "has been carefully examined by the Bureau of Manufactures and Commerce at Berlin, and has been found, in adaptability and

* Prepared chiefly from a biographical sketch by Capt. O. E. Michaelis, U. S. A.

intrinsic excellence, fully equal to the best English steel, in some respects even preferable." But in spite of the good quality of the metal, the demand was very light, and there was not business enough to pay expenses. The pleasant home had to be abandoned, and the family went to live in a small one-story laborer's cottage still standing in the heart of the immense establishment which the genius of the owner's son reared around it.

It was in this humble cottage that Alfred Krupp lived while laying the foundations of the industry that is now known the world over. In 1873 he had an engraving made of the house, copies of which were distributed to the workmen with a note saying, among other things:

> "Fifty years ago this laborer's cot was the refuge of my parents. May no workman of ours ever experience the sorrow that then enshrouded us! For twenty-five years the issue was in doubt, an issue which has since then, by degrees, so astonishingly rewarded the privations, the struggles, the confidence and the perseverance of the past. May this example stimulate others in distress, may it increase the respect for small domiciles and the sympathy for the greater cares that often dwell therein."

Shortly before Friedrich Krupp's death, he told his son the secret of making cast steel. In 1826, his widow announced that the works would be continued under the former name and manufacture "cast steel in rods of any thickness, rolled plates and forgings after drawings or models, such as mint dies, shafting, spindles, shear-blades, rolls, etc., also tanners's tools." The management of the little plant, which had been a commercial failure under Friedrich Krupp, passed into the hands of his son before the latter was fifteen years of age. With two workmen he labored daily at the forge, and his condition at the time is indicated best by his own words:

> " Working hard, often all night long, my food being for the most part potatoes, coffee, bread and butter, but no meat, I felt all the responsibility of a harassed father of a family. For twenty-five years I persevered, until at last, under gradually improving circumstances, I conquered a decent living. My most vivid impression of the distant past is the recollection of the long-continued, ever-threatening danger of ruin, and its avoidance through patience, self-denial and labor."

For a period of about fifteen years, just enough was earned to pay the workmen and living expenses. Under the direction of an uncle, he studied book-keeping and mercantile methods, and gradually extended the market for his steel. In 1832 he had ten workmen, and somewhat later made his first important commercial success, the sale of English patents for a cast-steel roller die. All his spare money was apparently devoted to increasing his plant and for journeys of investigation among English steel works. Early in the forties, he began experimenting with cast-steel guns, and by 1845 the number of employees had risen to 122, although during the agricultural depression and political troubles of 1848, the number fell off for a time. During

the latter year Alfred Krupp assumed entire control of the establishment, his brother Friedrich withdrawing, and in a short time the works began to grow in size and importance at a surprising rate. In 1848 the number of men was 72; in 1858, 1 047, and in 1863, 4 185. The most important advances were made between 1850 and 1860. In 1851, Krupp showed at the London Exhibition a cast-steel block weighing over 2 tons, something unheard of in England at the time; in fact, it was so frequently reported that the steel was not of good quality and would fly to pieces like cast iron under the hammer, that a piece had to be cut from the block and forged on the anvil to prove its quality. The next year was marked by the Krupp invention of a method of manufacturing weldless railway ties, which proved very profitable.

In 1853 Krupp married Bertha Eichhoff and left the little cottage, where he had lived during the building up of the works, for an unpretentious two-story house adjoining it. It was here that the present owner of the works, Friedrich Alfred Krupp, was born, and here the family lived until 1864, when they moved to a larger house, also within the limits of the works. Afterward a small country home, a few miles from Essen, was purchased and gradually enlarged. It is worth noticing that for more than forty years the builder of this great establishment lived within its boundaries, most of the time in a house far inferior to that occupied by many of his employees.

The successful exhibit at London was far surpassed by that at Paris in 1855, where a block weighing 5 000 kilos was shown, which received a gold medal. By this time the manufacture of guns was well advanced, and a 12-pounder shell gun which was among the exhibits was subjected to many trials. This did not lead to an order, however. The first country to order guns was Egypt, in 1857, followed soon by Brunswick and Prussia. About this time he designed his first rifled breech-loaders, which were adopted by Prussia in 1861. In 1868 there was a competitive trial at the Tegel Proving Ground near Berlin between Krupp breech-loaders and Woolwich muzzle-loaders, in which the former proved far superior. From that time on the Krupp ordnance was recognized as among the best, and its service a few years later during the Franco-German war showed that the peace tests were equalled by the hard trials of actual fighting.

The numerous institutions founded by Krupp for the benefit of his employees have been often described and need not be mentioned here. His idea was that "with assured and sufficient earnings, with content and comfort at home, every individual can enjoy the very fact of living," and he endeavored to furnish these conditions as far as possible. His plans have much of the paternalism for which German institutions are noteworthy, but their success is demonstrated by the comparative absence in Essen of labor troubles, anarchistic and even socialistic-

democratic agitations, as compared with other important industrial centers in that country.

The success which was achieved by this man was remarkable. In sixty years he won his way from being the boy manager of a nearly insolvent forge, worked by two men besides himself, to the proud position of the heaviest individual tax-payer in the German Empire and the sole owner of a business on which 60 000 people depended for a living. Honors and orders of all sorts were given him by many governments, yet he rarely wore a decoration. Kings, emperors and princes were often among his guests, yet he declined the offer of a title, and preferred to retain the name which his energy had made a guarantee of good material and workmanship.

Early in 1887 his health began to fail. For some years, he had been gradually withdrawing from the business of the works, and leaving the management to a committee of technical, commercial and legal experts of which his son was a member, so when his end drew near there was no hitch in the operations of the establishment, a result he had worked for during a number of years. His strength finally gave out, and on July 14th, 1887, he passed away gently, in the seventy-fifth year of his age.

He was elected a Fellow of the American Society of Civil Engineers on June 14th, 1870.

THOMAS C. DURANT, F. Am. Soc. C. E.

Died October 5th, 1885.

Thomas C. Durant was born in Lee, Berkshire County, Mass., in 1820, and came of a family which had played a prominent part in the early history of that region. He studied medicine at the Albany Medical School and practiced for about three years, but finally gave up the profession to enter upon the business career in which he subsequently achieved remarkable success. He became a member of the Albany shipping firm of Durant, Lathrop & Company, which had branches in New York, Chicago and Boston, and carried on a large business. Dr. Durant was the head of the New York branch. He was the owner of a number of vessels, leased many more, and his European trade, particularly in wheat, was very profitable up to about the time of the French Revolution of 1848.

The shipping interests with which he was connected led him to recognize the possibilities of the West, and made him a strong advocate of internal improvements which would open up the resources of that

region. He was actively engaged in promoting the interests of the Michigan Southern Railroad, and was one of the leading contractors for the construction of the Peoria and Bureau Valley and the Mississippi and Missouri Railroads. He made surveys for a railway line in the Platte Valley several years before the organization of the Union Pacific Company, and in 1863 had surveys made at his own expense from Omaha to the basin of Great Salt Lake. In 1863 he took an active part in raising the $2 000 000 stock subscription required by Congress before the Union Pacific Company could be organized. His active interest in the work continued until the last rail was laid, the financiering of the great undertaking receiving most of his attention.

As soon as this line was finished Dr. Durant began building the Adirondack Railroad, of which he was the chief stockholder, President and General Manager at the time of his death.

He was elected a Fellow of the American Society of Civil Engineers on November 18th, 1870.

FREDERICK W. MERZ, F. Am. Soc. C. E.*

Died December 8th, 1883.

Frederick W. Merz was born in Germany in 1832, and came to this country about 1850. He was a mechanic in Louisville and opened a shop there for making architectural ironwork and doing general blacksmithing. His early work was on a small scale, and his financial resources were evidently not large, for his first anvil, weighing 140 lbs., he carried on his shoulders from the store where it was purchased to his shop, four or five blocks distant. In the course of time his business grew steadily; by 1870 he had a shop employing about a hundred hands and did a fair share of the architectural ironwork in and near Louisville, Ky. Later on, the business was incorporated, and Mr. Thomas J. Wood was associated with him. He acquired considerable property, and withdrew from his Louisville business four or five years before his death. He went to New York and there lost nearly all his estate, which so preyed on him that he became insane. He was in an asylum in New York for a time, but recovered and went to Louisville. He was attacked a second time, late in 1883, and died at the Central Kentucky Asylum for the Insane, at Lakeland, on December 8th, 1883, of paralysis.

Mr. Merz was elected a Fellow of the American Society of Civil Engineers on May 28th, 1872.

* Memoir prepared from information furnished by W. R. Belknap, F. Am. Soc. C. E.

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OF

CIVIL ENGINEERS

December, 1896

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Edited by the Secretary, under the direction of the Committee on Publication.

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ILLUSTRATION.

The price of publications is as follows: Proceedings, $6 per annum; Transactions, $10 per annum. Postage will be added when they are sent to foreign countries.

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ON ANALYSIS OF IRON AND STEEL:—Sub-Committee of the American Society of Civil Engineers (of the International Committee on Standards for the Analysis of Iron and Steel, of which Prof. J. W. Langley is Chairman)—Charles B. Dudley, William Metcalf, Thomas Rodd, A. E. Hunt.

ON UNITS OF MEASUREMENT:—George M. Bond, William M. Black, R. E. McMath, Charles B. Dudley, Alexander C. Humphreys.

The rooms of the Society are open from 9 to 17 o'clock each business day, except Saturday (when they are closed at 15 o'clock), and at other times on application to the Janitor.

HOUSE OF THE SOCIETY—127 EAST TWENTY-THIRD STREET, NEW YORK.

Vol. XXII. DECEMBER, 1896. No. 10.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PROCEEDINGS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

SOCIETY AFFAIRS.

CONTENTS:

MINUTES OF MEETINGS.

OF THE SOCIETY.

December 2d, 1896.—The meeting was called to order at 20.15 o'clock, President Thomas Curtis Clarke in the chair; Charles Warren Hunt, Secretary, and present, also, 57 members and 6 visitors.

The President announced that all arrangements for immediately beginning the construction of the new house of the Society had been completed. The plans had been carefully considered before adoption, and the contract for construction was let at a lower price than was anticipated.

The Secretary read a letter from Mr. Albert Ladd Colby, Secretary *pro tem.* of the Association of American Steel Manufacturers, transmitting the following resolutions of that body :

" *Resolved*, that we, the Association of American Steel Manufacturers, endorse the decimal system as the proper standard for measuring all materials.

" *Resolved*, that the Secretary be requested to forward a complete copy of the committee's report, together with a copy of these resolu-

tions, to the Secretaries of the American Institute of Mining Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers, and the American Railway Master Mechanics' Association, as an evidence of the appreciation of the work accomplished by these societies towards the establishment of the decimal system of gauging, and as a proof of the hearty co-operation of this Association in this movement."

Upon motion duly seconded, the reading of the report referred to in the resolutions was postponed.

A paper by M. S. Parker, M. Am. Soc. C. E., entitled "Governing of Water Power Under Variable Loads," was presented by the Secretary, who read correspondence on the subject from Joseph P. Frizell, M. Am. Soc. C. E., and Mr. Mark A. Replogel. The paper was discussed orally by Messrs. A. McL. Hawks, J. Waldo Smith, S. Whinery and John Bogart.

Ballots were canvassed and the following candidates declared elected:

As Members.

Albert Irvin Frye, San Francisco, Cal.
Edwin Dwight Graves, Hartford, Conn.
Lee Treadwell, Pencoyd, Pa.
Reid Whitford, Georgetown, S. C.
Sydney Bacon Williamson, Florence, Ala.

As Associate Members.

Fritz Carl Anders Georg Bergengren, Harrisburg, Pa.
Frank Henry Constant, Minneapolis, Minn.
Walter Frick, Carbondale, Pa.
William Burnet Yereance, South Orange, N. J.

The Secretary announced the election by the Board of Direction on December 1st, 1896, of the following candidates:

As Associate.

Edward Alverson Rogers, New York City.

As Juniors.

Alexander Johnson, Brooklyn, N. Y.
Edgar Day Knap, New York City.
Francis Lansing Pruyn, Brooklyn, N. Y.
William Belden Reed, Jr., New York City.
Joseph Harrison Wallace, Holyoke, Mass.
Charles Royce Ward, Troy, N. Y.

The Secretary announced the death on November 28th, 1896, of John Russell Thomas, elected Member on October 5th, 1881.

Adjourned.

December 16th, 1896.—The meeting was called to order at 20.20 o'clock, President Thomas Curtis Clarke in the chair; Charles Warren Hunt, Secretary, and present, also, 68 members and 22 guests.

Two papers were presented and discussed jointly, one by Edward P. North, M. Am. Soc. C. E., entitled "The Influence of Rails on Street Pavements," and the other by James Owen, M. Am. Soc. C. E., entitled "Car Tracks and Pavements." The Secretary read correspondence on these papers from Messrs. G. L. Wilson, F. W. Cappelen, W. G. Price, W. T. Jennings, Horace Andrews, O. H. Tripp, S. Whinery, W. Katté and A. A. Schenck, and they were further discussed by Messrs. G. J. Fiebeger, N. P. Lewis, J. W. Howard, W. B. Reed, H. C. Meyer, M. D. Pratt, T. C. Clarke, G. E. Waring, Jr., J. M. Evans and E. P. North.

The Secretary announced the deaths of David Leonard Barnes, M. Am. Soc. C. E., and Alexander Samuel Diven, F. Am. Soc. C. E.

Adjourned.

OF THE BOARD OF DIRECTION.

(Abstract.)

December 1st, 1896.—Eleven members present.

The question of the advisability of the appointment of a Special Committee to report on the proper manipulation of tests of cement, referred to the Board of Direction, under Article VI, Section 13, of the Constitution, by the Society at the meeting held November 4th, 1896, was considered.

Action was taken in regard to the financing of the scheme for the New Society House, and the contract for the erection of the New Society House was awarded to Charles T. Wills, of New York City.

Applications were considered and other routine business transacted.

One candidate was elected as Associate, and six as Juniors.

Adjourned.

ANNOUNCEMENTS.

MEETINGS.

Wednesday, January 6th, 1897, at 20 o'clock, a regular meeting will be held, at which a paper by Jules Breuchaud, Assoc. Am. Soc. C.E., entitled, "The Underpinning of Heavy Buildings," will be presented. This paper is printed in this number of *Proceedings*.

Wednesday, February 3d, 1897, a regular meeting will be held, at which a paper by John Findley Wallace, M. Am. Soc. C. E., entitled,

"The Substitution of Electricity for Steam as a Motive Power for Suburban Traffic," will be presented. This paper is printed in this number of *Proceedings*.

ANNUAL MEETING.

Wednesday and Thursday, January 20th–21st, 1897, the Forty-fourth Annual Meeting of the Society will be held. The Business Meeting will be called to order at 10 o'clock on Wednesday morning, when the Annual Reports will be read, officers for ensuing year elected, time and place for the next Annual Convention discussed, and other business transacted.

The programme in detail is now being arranged by a special committee appointed for the purpose, and it is probable that the following will be carried out.

At a meeting to be held on Wednesday evening, January 20th, the Secretary will give an historical sketch of the Society. On Thursday there will be an excursion to the Cornell Dam of the Croton Water-Works, and on the evening of that day a reception will be held.

DISCUSSIONS.

Discussion on the paper by George E. Gray, Hon. M. Am. Soc. C. E., entered "Notes on Early Practice in Bridge Building," and the paper by Charles Carroll Gilman, F. Am. Soc. C. E., entitled "Experiments with a New Method of Heating and Ventilation," which were presented at the meeting of November 18th, 1896, will be closed January 1st, 1897.

Discussion on the paper by M. S. Parker, M. Am. Soc. C. E., entitled "Governing of Water Power under Variable Loads," which was presented at the meeting of December 2d, 1896, will be closed January 15th, 1897.

Discussion on the paper by Edward P. North, M. Am. Soc. C. E., entitled "The Influence of Rails on Street Pavements," and the paper by James Owen, M. Am. Soc. C. E., entitled "Car Tracks and Pavements," which were presented at the meeting of December 16th, 1896, will be closed February 1st, 1897.

Discussion on the paper by Jules Breuchaud, Assoc. Am. Soc. C. E., entitled "The Underpinning of Heavy Buildings," which will be presented at the meeting of January 6th, 1897, will be closed February 15th, 1897.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

		Date of Membership.
Edes, William Cushing	321 Market St., San Francisco, Cal	Nov. 4, 1896
Graves, Edwin Dwight	Box 748, Hartford, Conn.	Dec. 2, 1896
Llewellyn, Francis John	Vice-Pres. and Chf. Eng., Gillette-Herzog Mfg. Co., Minneapolis, Minn	Nov. 4, 1896
Savage, Hiram Newton	National City, Cal	Oct. 7, 1896
Vaughan, George Washington	N. Y. C. and St. L. R. R., Box D, Cleveland, Ohio.	Nov. 4, 1896
Whitford, Reid	U. S. Asst. Eng., U. S. Eng.'s Office, Georgetown, S. C	Dec. 2, 1896

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Frick, Walter	City Engineer, Carbondale, Pa	Dec. 2, 1896
Kinsey, Warren Rue	108 Fulton St., New York City	Mar. 4, 1896
Tripp, Oscar Holmes	Rockland, Me	Oct. 7, 1896
Vorce, Clarence Browning	Stamford, Conn	Oct. 7, 1896
Yereance, William Burnet	Box 46, South Orange, N. J	Dec. 2, 1896
Wing, Charles Benjamin	Professor of Bridge Engineering Leland Stanford, Jr., University, Santa Clara Co., Cal	Nov. 4, 1896

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Rogers, Edward Alverson	372 Manhattan Ave., New York City	Dec. 1, 1896

JUNIORS.

Harding, William Stewart	3411 Hamilton St., Philadelphia, Pa	Nov. 3, 1896
Haring, Alexander	Mohawk, N. Y	Nov. 3, 1896
Reed, Jr., William Belden	162 West 121st St., New York City	Dec. 1, 1896
Wallace, Joseph Harrison	7 Main St., Holyoke, Mass.	Dec. 1, 1896

CHANGES AND CORRECTIONS.

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WILSON, FRANK WALTER............Care of W. E. Weeks, P. O. Box 3129, Johannesburg, South African Republic.

DEATHS.

BARNES, DAVID LEONARD...........Elected Member, July 2d, 1890; died December 15th, 1896.
DIVEN, ALEXANDER SAMUEL.........Elected Fellow, June 16th, 1870; died June 11th, 1896.
THOMAS, JOSEPH RUSSELL...........Elected Member, October 5th, 1881; died November 28th, 1896.

ADDITIONS TO

LIBRARY AND MUSEUM.

From American Book Co., New York, N. Y.:
A Text Book of Plane Surveying.

From American Society of Mechanical Engineers, New York, N. Y.:
Advance Papers Nos. 707 to 717, as follows: Report of Progress of the Committee on Fireproofing Tests; History and Technical Sketch of the Origin of the Bessemer Process; Ancient Pompeiian Boilers; Experimental Investigation of the Cutting of Bevel Gears with Rotary Cutters; The Moment of Resistance; Contraction and Deformation of Iron Castings in Cooling from the Fluid to the Solid State; The Washing of Bituminous Coal by the Luhrig Process; Some Special Forms of Computors; Steam Engine Governors; Method of Determining the Work Done Daily by a Refrigerating Plant and its Cost; A 200-Foot Gantry Crane; Efficiency of the Boiler Grate; A Method of Determining Selling Price; Paper Friction Wheels; Rustless Coatings for Iron and Steel; Friction Horse Power in Factories.
Transactions, Vol. XVII, 1896.

From Atchison, Topeka and Santa Fé Railway Company, Topeka, Kan.:
First Annual Report for six months ending June 30th, 1896.

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From Boston Public Library, Boston, Mass.:
Monthly Bulletin of Books Added. Vol. 1, Nos. 9, 10. November, December, 1896.

From Captain O. M. Carter, Savannah, Ga.:
Annual Report upon the Improvement of Rivers and Harbors in Eastern Georgia.

From City of Montreal, Can.:
Annual Reports for the year 1894.

From Field Columbian Museum, Chicago, Ill.:
Annual Report of the Director for the year 1895-96.

From E. Sherman Gould, Yonkers, N. Y.:
A Primer of the Calculus.

From Edward B. Guthrie, Buffalo, N. Y.:
Annual Report of the Department of Public Works of the City of Buffalo, N. Y. for the year ending December 31st, 1895.

From M. L. Holman, St. Louis, Mo.:
Photographs of St. Louis Water-Works; Low Service Pumping Engine; Interior of Engine House; Low Service Pumping Station; Engine No. 6.

From Institution of Civil Engineers, London, Eng.:
Minutes of Proceedings, Vol. CXXVI.
Brief Subject Index, Vols. CXIX to CXXVI.

From Kansas University, Lawrence, Kas:
The University Quarterly, October, 1896.

From Lehigh University, South Bethlehem, Pa.:
The Courses in Mining Engineering, Citizenship and Technical Education.

From George S. Morison, Chicago, Ill.:
Report of Mechanical Tests at Watertown Arsenal, Mass., on Steel Wire Cable from the Trenton Iron Co.

From Nederlandsche Vereeniging voor Electrotechniek, Hague, Holland:
Nutulen der Vergadering van 13 Mei, 1896.

From Patent Office, London, Eng.:
Patents for Inventions; Abridgments of Specifications; Electric Telegraphs and Telephones; Sifting and Separating; Wood and Wood-Working Machinery; Beverages, Fabrics, Dressing and Finishing Woven and Manufacturing Felted; Closets, Urinals, Baths, Lavatories and Like Sanitary Appliances; Philosophical Instruments; Grain and Seeds, Treating; Sewage, Treatment of; Cooling and Ice Making; Grinding, Crushing, Pulverizing and the Like; Printing; Fastenings, Dress; Cutting, Punching and Perforating Paper; Iron and Steel Manufacture.

From Royal Society of New South Wales, Sydney, N. S. W., through George Robertson & Son, London, Eng.:
Journal and Proceedings, Vols. X to XXVII, and XXIX for 1876 to 1893, 1895.

From I. M. de Varona, Brooklyn, N. Y.:
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From U. S. Department of the Interior, Census Division:
Report on Farms and Homes; Proprietorship and Indebtedness in the United States at the Eleventh Census, 1890.

From U. S. Navy Department:
Report of the Surgeon-General, U. S. N., 1896.
Annual Report of the Chief of the Bureau of Steam Engineering, 1896.

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Twenty Specifications for the Improvement of Certain Rivers and Harbors.

1896. DECEMBER. No. 10.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS.

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CONTENTS.

THE UNDERPINNING OF HEAVY BUILDINGS.

By JULES BREUCHAUD, Assoc. Am. Soc. C. E.

TO BE PRESENTED JANUARY 6TH, 1897.

This paper is a description of a novel method recently adopted for the support of heavy buildings.

The first instance of which mention will be made is in connection with the foundation work for the Commercial Cable Building, twenty-one stories high, at Broad and New Streets, New York City. The lot

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

occupied by the new building is 45 ft. wide on Broad Street and 55 ft. on New Street, and is 160 ft. in length.

The plan required an unusually deep excavation which was to contain two stories below the level of the street, the total depth from the sidewalk to the under side of the concrete floor being 30 ft. on Broad Street and 36 ft. on New Street.

The lower story and a part of the next, being below the water level, had to be made water-tight, and in order to obtain that result the plan included, on each side of the lot, a continuous line of rectangular caissons to be put in place by the plenum pneumatic process. Other caissons, circular in form, were also sunk in the central portion of the lot for the support of the middle rows of columns. There are 39 caissons, including those which are rectangular and circular.

All these caissons, the rectangular ones generally 9 x 18 ft. and 6 x 14 ft., and the circular ones from 8 ft. to 9½ ft. in diameter, were sunk to the underlying ledge which was found to be from 45 ft. to 50 ft. below the sidewalk. Fig. 1 shows the arrangement of all the caissons. The original soundings indicated that the surface of the rock was at a higher elevation, but actual excavation showed that it was lower than expected, and that an important layer of hard-pan from 5 ft. to 14 ft. in thickness must be gone through before rock could be reached.

The contract for the foundations contained the usual provision making the contractors responsible for any damage to adjacent buildings, resulting from their operations. This made it necessary to devise means for supporting the buildings, while the depth to be reached and the necessity for economizing space, where so many caissons and their accompanying coffer-dams had to be handled, made it important that as little room as possible be occupied by the supports necessary to maintain the surrounding buildings.

As compared with other work of the same class heretofore executed in that vicinity, the problem of supporting the adjacent buildings was unusually difficult in this case, as the plans provided for the placing of the rectangular caissons almost contiguous with one another and exactly on the boundary lines of the lot, an arrangement which had not been previously attempted.

The attention of the author had already been called to the fact that considering the increasing height of the buildings which are now being erected for business purposes on comparatively small areas, a

limit would soon be reached beyond which it would not be economical, or even practicable or safe, to use timber supports, even of such special and ingenious design as have been recently adopted for such purposes.

The peculiar conditions under which the work had to be done in this case led to the conclusion that it would be desirable to resort to such devices as would leave the limited space at hand entirely free from interference, and open at all times for the free handling of the pneumatic, hoisting and other plants, for the movement of bulky caissons and for placing them strictly on the boundary lines of the lot. This latter result was literally accomplished, the rivets of the steel caissons in their downward progress leaving, in many instances, their marks on the brick surfaces of the adjacent walls.

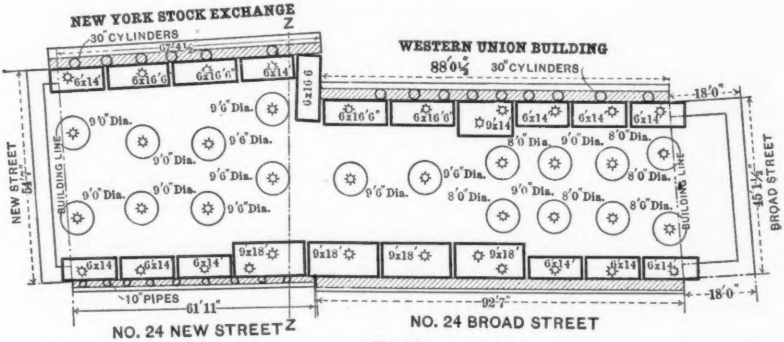


Fig. 1.

The method followed consisted of placing vertical iron supports directly under the walls to be supported in the following manner:

After determining the number of supports necessary for supporting the superincumbent weight, a vertical slit was cut into the wall from the bottom upward, for a distance depending on local circumstances, generally from 10 ft. to 12 ft., the slit being of such a width as would amply accommodate the pipe which had been determined to be sufficient in diameter for each case. On the top of that slit a short transverse horizontal cut was made, in which one or more iron I-beams were built. The iron column or pipe which was to support the wall being divided into pieces of proper length, which could be either screwed together or united by means of bolted interior flanges, the first length was placed on end on the ground in the slit of the wall. Blocking being then placed on the top of the pipe, a jack was inserted

between the pipe and the short I-beams built on the top of the slit, and either by simple pressure or with the aid of a water-jet, the first pipe was pushed down, by alternate jacking and blocking, to its full length. Next, a second piece of pipe was fastened on top of the first, and the sinking operation was resumed until another pipe could be added to the second, and so on until the pipe had reached bed-rock, or such other support as was sufficient.

The top of the highest pipe was left at about the level of the bottom of the wall, in which another set of short horizontal I-beams was built, reposing on the top of the pipe. Vertical beams or columns were then firmly wedged between the two sets of horizontal I-beams, and the slit in the wall was filled up with brickwork. These vertical beams were used to avoid the compression which would otherwise occur in the fresh masonry built in the vertical slit.

Only one or two supporting pipes were, obviously, driven at a time, in order to avoid excessive concentration of weight on the other parts of the foundation while the pipes were being sunk.

The first trial of this method was made under the small building at the southwestern corner of the lot, it being desirable to proceed with caution. This building is only four stories high, but its brick wall was supported on a stone foundation of the worst description, 24 ins. thick, it being composed of small stones without bond, laid in so-called mortar without cohesion, which, at many places, could be easily blown off. The importance of keeping the building uninjured was increased by the fact that a restaurant business was conducted in the basement, and that an interruption of it would have caused a serious pecuniary loss to the contractors, who, as before stated, were held responsible for the proper maintenance of the adjoining buildings.

Considering that the distance from the bottom of the foundation wall of that building was 33 ft. from the hard-pan on which the supporting pipes were carried, and 23 ft. from the bottom of the cellar excavation intended for the new structure, the case required careful handling. Notwithstanding the small weight of the building, nine pipes were used on a total length of 57 ft. They are heavy steam pipes 10 ins. in diameter, $\frac{3}{8}$ in. thick, having a cross-section of 12 sq. ins., and weighing about 40 lbs. per lineal foot. They were sunk in lengths of 5 ft., connected together with outside couplings and butt joints. Every alternate pipe contained a smaller interior one, placed so as to

break joints, the annular space between them being filled with Portland cement grout. All the pipes were ultimately filled with Portland cement concrete. Each pipe was driven into the hard-pan to a firm bearing by working the jack to its full capacity of 60 tons, which is more than the weight that each pipe has to carry. No movement of any kind occurred during or after the sinking of the pipes.

The success attending this preliminary operation led to the adoption of the same method for the support of the buildings on the north side, the Western Union and Stock Exchange Buildings, with such

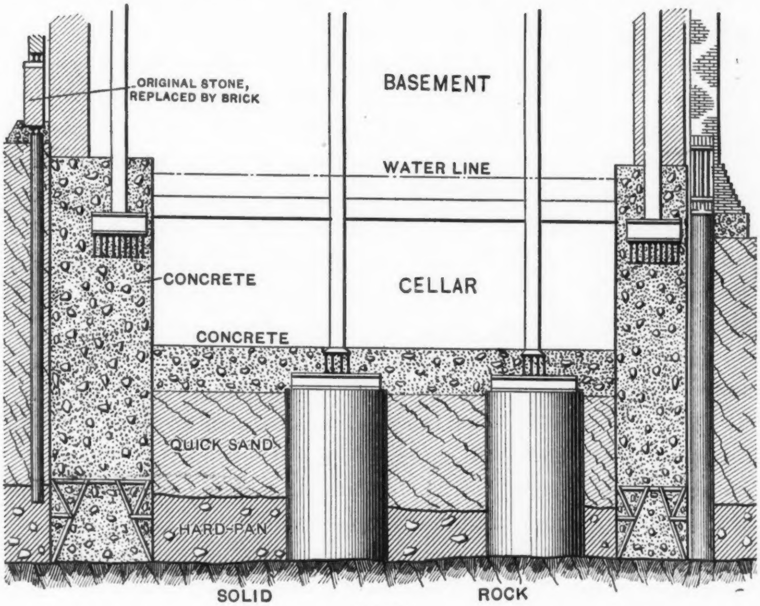


Fig. 2.

modifications and improvements as were rendered necessary by the greater weights of these structures, the Western Union Building being seven stories high and the other less.

The Western Union Building is built on piles extending about 17 ft. below the base of the walls, the points of the piles being consequently a few feet above the bottom of the new excavation. Nine pipes were sunk to support it. In this case it was found desirable to extend the supporting pipes to the rock bottom, thus making it necessary to force them through many feet of hard-pan, which could not be dis-

placed by jet and in which boulders might be found in the path of the pipes. In order to overcome these difficulties and to render it possible to level up the rock bottom on which the pipes were to rest, the pipes were made of cast iron, 28 ins. in interior diameter. This size made it practicable to send a man down for the purpose of excavating the hard-pan by hand in and under the edge of the pipe, of preparing intervening boulders for blasting, and of preparing the rock bottom when unsound or sloping, and of firmly wedging the bottom of the pipe thereon. Those operations, owing to the presence of water in the ground, had to be carried on in compressed air, a portable and easily connected air-lock being provided for the purpose.

One of the lower pipes having been injured by forcing it down past a large boulder, the rest were subsequently made of riveted steel plates. Although boulders were encountered and blasted, and, in several instances, piles had to be extracted on account of their projecting into the lot of the new building, no serious difficulty was found in preparing for and sinking all the pipes, which were afterwards filled with concrete. Generally, two men, alternately jacking and blocking, were sufficient to drive the pipes, when once placed. No movement occurred in the Western Union Building.

The foundation of the Stock Exchange was similarly treated, six supporting pipes being used on a total length of 68 ft.

The next application of the same method was at the northwest corner of Cedar and William Streets for the support of the Stokes Building, a heavy structure, 11 stories high, pending the preparation of the adjoining foundation for the Queen's Insurance Building.

The Queen's Insurance Building is supported on pile foundations carrying grillages of steel beams which support the columns. The piles were cut off 1 ft. below the natural water level at the site, or about 18 ft. below the street level. The earth was excavated 1 ft. below the cut-off, and the concrete floor, 4 ft. thick, laid over the entire site.

The material at the site is of the same general character as often found elsewhere in the lower part of New York City, being quicksand underlaid by hard-pan and bed-rock. The preliminary borings indicated the existence of bed-rock 30 ft. below floor level.

The foundations of the Stokes Building are spread on the surface of the sand without supporting piles, and are estimated to carry 45

tons per lineal foot of wall. Unfortunately, when this building was constructed, the base of the foundation was placed about 2 ft. above the cellar floor of the adjoining building, now removed to make room for the construction of the Queen's Building (see Fig. 5). It was believed that the concussion of driving piles for the foundation of the Queen's Insurance Building would cause a flow of quicksand from underneath the wall of the Stokes Building, and consequently damage the structure.

The columns for supporting the Stokes Building are of cast iron,

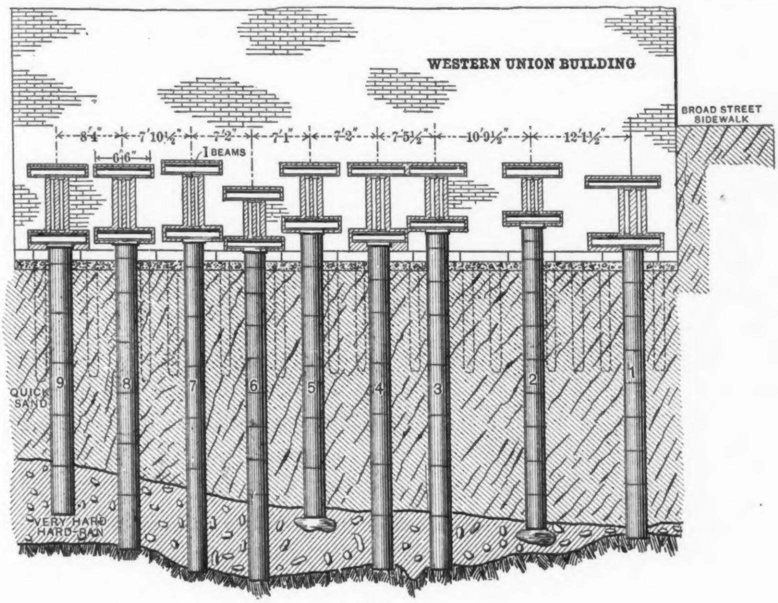


FIG. 3

33 ins. in exterior diameter and 1½ ins. thick. When the work of placing them was taken in hand, it was found that the borings were misleading, and the material supposed to be bed-rock proved to be firm hard-pan of considerable depth, in fact the first column was driven into it a distance of 16 ft. without finding any indication of rock. To persist in the attempt to reach bed-rock would have entailed an expenditure of a large amount of time and money without commensurate results, and it was decided to found the pipes on hard-pan. This material, being very compact, is capable of carrying a great load, especially at a

considerable depth below the surface; however, as its limit of bearing capacity is unknown, it was thought prudent to enlarge the base of the column by excavating outside the cutting edge and placing an annular steel ring on which the cutting edge was to rest. This ring, which extended 3 ins. outside the column and 4 ins. inside, was in sections and was composed of plates 1½ ins. in thickness.

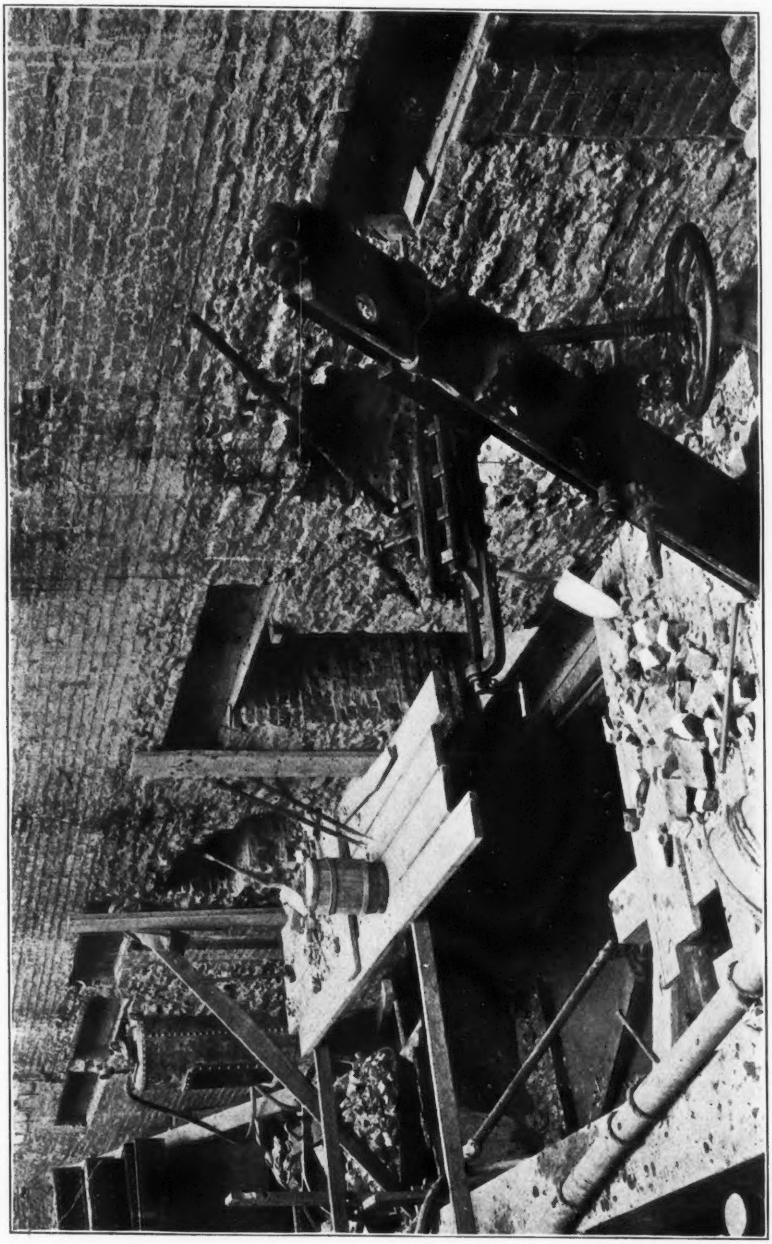
The number of cylinders was not increased on account of the change in the foundation, and the pressure on the enlarged base, without deduction for friction on the sides of the columns, was in the neighborhood of 40 tons per square foot, which is, of course, much greater than would be placed on masonry of the best character above ground. With due allowance for friction on the sides of the columns, the net load is supposed to be about 36 tons per square foot. Both these figures are doubtless in excess of the actual load, as the old foundation continues to bear some indeterminate part of the weight it formerly carried.

This work, including seven columns 33 ins. in diameter, was completed in seven weeks, without mishap of any kind, and the numerous piles for the new building were subsequently driven without injury to the Stokes Building.

Another high building, at the northwest corner of Wall and Nassau Streets, was also supported by similar means, the columns in that case being thirteen in number and made of lap-welded steel pipes ⅜ in. in thickness and 16 ins. in diameter. This work was, it is reported, carried through successfully.

Referring to the illustrations (Fig. 1) gives the plan of the Broad Street foundation, showing the position of the 39 caissons and of all the pipes sunk under the walls of the adjoining buildings. Fig. 2 is a cross-section at a point where the lot widens. Fig. 3 shows the elevation of the rock bottom, the depth of hard-pan, and the position of all the supporting pipes. Fig 4 is a section of the supporting wall at one of the columns under the Western Union Building. Fig. 5 is a section of the wall of the Stokes Building, showing one of the supporting columns. Plate XVII is a view of the south wall of the Western Union Building, showing various phases of the operations for placing the supporting columns. Beginning at the right, the first, fifth and seventh columns are in place, and the operation completed. For the second and fourth, the cutting of the vertical slit is being

PLATE XVII.
PAPERS AM. SOC. C. E.,
DECEMBER, 1896.
BREUCHAUD ON UNDERPINNING HEAVY BUILDINGS.



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made, close drilling being resorted to in this case, owing to the great hardness of the brickwork. At the third column the two sets of horizontal beams are in place, leaving only the vertical cut to be filled. The sixth column carries the air-lock while it is being sunk into the hard-pan.

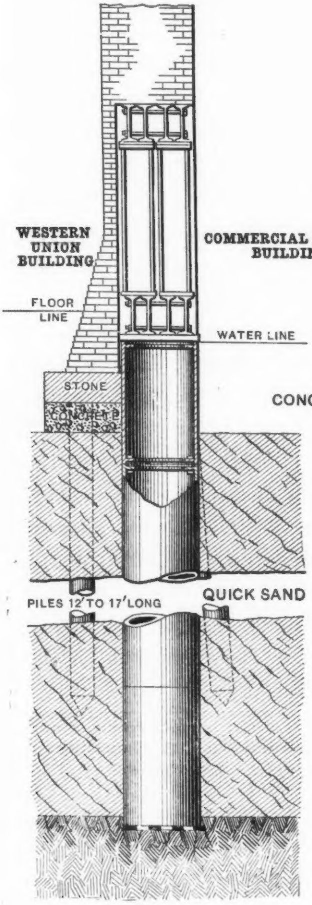

FIG. 4.

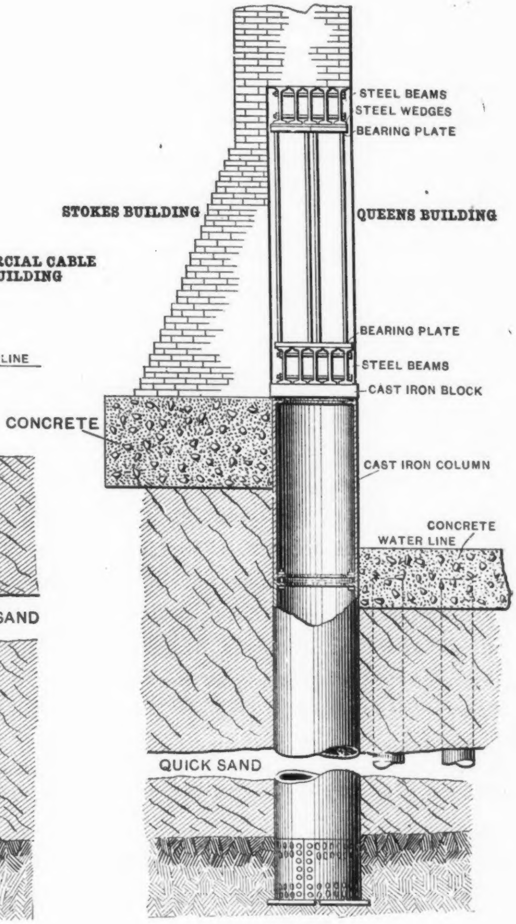

FIG. 5.

Although the author does not wish it to be understood that the method above described is recommended as of universal application, he believes that in many cases, especially when the weights to be carried are great, and when the character of the ground is such that it be-

comes desirable to transfer the weight of the building to a deeper and harder foundation, the new method is safer than those heretofore used and that it gives security economically. It has the advantage of leaving the ground which is to be built upon free from obstructions, thus preventing the costly and risky practice frequently resorted to of shifting the artificial supports during construction. The absence of interference with the inside of the adjoining buildings would often be a sufficient incentive to the adoption of this method; a lasting benefit can also be secured from the fact that the adjoining buildings remain rigidly supported, thereby avoiding the usual, although often small, movements which follow the removal of the artificial supports used during the period of construction. Although other applications of the method may obviously present themselves in the general field of construction, the author prefers to leave others to draw their own conclusions, his object being only to describe the work done.*

The architects and consulting engineer for the Commercial Cable Company and Queen's Insurance Buildings were Messrs. Geo. Edward Harding & Gooch and John Bogart, M. Am. Soc. C. E., respectively. The contractors for the foundations were Messrs. Arthur McMullen & Co., of which firm the author is a member. In the execution of the work, the use of underpinning columns was devised by the author. The services of John F. O'Rourke, M. Am. Soc. C. E., were secured in the preparation of the preliminary plans and estimates for the Commercial Cable Building work, and the services of Alfred Noble and T. Kennard Thomson, Members Am. Soc. C. E., and Mr. Byron Goldsboro, Superintendent, were secured for the operations on the Commercial Cable and Queen's Insurance Buildings.

* It has been thought unadvisable to burden this paper with too many details of construction, but if further information is desired, a detailed description of the foundations of the Queen's Insurance Building will be found in the *Engineering Record* of August 8th, 1896.

1896. DECEMBER. No. 10.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

PAPERS.

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THE SUBSTITUTION OF ELECTRICITY FOR STEAM AS A MOTIVE POWER FOR SUBURBAN TRAFFIC.

By JOHN FINDLEY WALLACE, M. Am. Soc. C. E.

TO BE PRESENTED FEBRUARY 3D, 1897.

It is not the intention of the author in this paper to treat exhaustively of the question of the substitution of electricity for steam in the handling of heavy suburban traffic, but rather to give a concise statement of the history and results of certain investigations made by him, in order to bring out a full and free discussion of the subject from members of the Society and others who may be more competent to speak concerning it, to the end that the *Transactions* of the American Society of Civil Engineers may contain a record of the progress which has been made in the use of electric motors for transportation purposes, and to lay the foundation for future papers on this subject. The author does not pretend to any expert electrical knowledge, and requests an open criticism of any remarks made herein by experts in this branch of engineering, hoping that it will draw out valuable discussion and information.

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. The papers with discussion in full will be published in the volumes of *Transactions*.

In December, 1891, the author was called upon by the management of the Illinois Central Railroad to examine into and report upon the practicability of transporting large numbers of passengers between Van Buren Street, in the city of Chicago, and the grounds of the World's Columbian Exposition. As it would not be economical to establish a special service for the short exposition period which could not be utilized thereafter, the question of substituting electricity for steam as a motive power to handle the regular suburban business of the Illinois Central Railroad was a necessary sequel to the original proposition. An examination was made of the principal electric street lines in various cities of the United States. At that date none of the railroad lines that were originally steam roads had adopted electricity as a substitute for steam. So far the application of electricity for transportation purposes in the United States had mainly been confined to its substitution for horse-power on street railway lines and in the establishment of new lines of this character, in which the units of transportation were necessarily small and were moved at frequent intervals through short distances. The problem naturally divided itself into three divisions:

First. Practicability.—(*a*) As to the possibility of carrying 10 000, 20 000 or 30 000 passengers per hour between the World's Fair site and Van Buren Street, in Chicago, by electricity. (*b*) The practicability, after the close of the World's Fair in 1893, of satisfactorily handling the suburban business of the Illinois Central Railroad by electric power.

Second. Economy.—(*a*) The cost of handling the World's Fair business between the Lake Front Park and the site of the Exposition by electricity, as compared with steam. (*b*) The cost of operating the suburban traffic of the Illinois Central Railroad by electricity instead of steam after 1893.

Third. Appliances.—(*a*) Line construction. (*b*) Power plant. (*c*) Motors and cars.

Granting that the application was practicable, the next question to be considered was economy. Should it be shown that it would be economical, the third question to be considered was the nature of the appliances to be used.

In order to secure the necessary data for an intelligent consideration of these problems, the prominent electric manufacturing com-

panies in the country were asked to submit in writing their answers to a list of questions. As it is, of course, not advisable to disclose the names of the companies giving the information contained herein, they will be designated as (*a*), (*b*), (*c*), (*d*) and (*e*). Following is a statement of the requirements and the questions submitted to each company, with their answers in regular rotation:

"In considering the question of passenger transportation facilities between the Lake Front Park, in the city of Chicago, and the Columbian Exposition in Jackson Park, it is desirable to know whether electric power can be applied for passenger service with economy. The following are the physical conditions:

"The track will be first-class standard gauge railroad track, and the maximum grade will not exceed one-half of 1 per cent. The distance between the terminal stations will be 7½ miles. Between these stations there will be practically no curvature. If possible, loops will be constructed at each end of the line, with a radius of about 300 ft. As a basis for the consideration of the question, it is estimated that trains should consist of one motor car and two trailers, with provisions for carrying 336 passengers. The dimensions of the motors and trailers would be from 36 to 40 ft. in length, with cross-seats, and the cars should be about 8 ft. wide in the clear on the inside. It has been estimated that these cars will weigh about 20 tons, loaded. It is desired that the speed should be about 20 miles per hour. It is estimated that the equipment required will be from 60 to 70 motors and from 120 to 140 trailers. Estimating that 112 passengers can be carried in each one of the cars, including the motor, each train would carry, as stated above, 336 passengers. Assuming that one train can be loaded and despatched from the terminal station each minute, the capacity per hour will be 20 160 passengers.

"Considering the above conditions and assumptions, in order to determine the advisability of adopting electric power, answers to the following questions are desired:"

Question 1.—What capacity should motors have in horse-power?

Answers.—(*a*) Capacity of motors, 75 H.-P. each, two on each axle.

(*b*) A 20-ft. motor car and two 40-ft. trail cars, as specified, could be operated at less than 75 H.-P. on an average, but the maximum required at starting, on grade and curve work, and with specially heavy loads, might raise these figures 50 to 75 per cent. It is, therefore, desirable to have, at least, two 75-H.-P. motors, one on each axle of the motor truck, and it is quite possible with the space at disposal to make these 100-H.-P. motors, that would be able to draw three or possibly four trail cars heavily loaded.

(*c*) The motor cars should have a capacity of 100 H.-P. each, but should be capable of developing up to 200 H.-P. for short periods of

time without harm or injury to any part. The best way to attain this result will be to employ two Eickemeyer-Field electric motors of 50 H.-P. each, one motor on each four-wheel swivel truck of the motor car.

(*d*) To handle a train of four cars, each weighing, when loaded, 25 tons, will require a draw-bar pull of nearly 1 000 lbs. This will mean a continuous development of about 50 H.-P. on the axle, and occasionally much greater power for acceleration, etc. We should, therefore, recommend four of our standard 25-H.-P. motors wound for 25 miles an hour. These will weigh each 2 500 lbs., approximately, so that four of them will add a weight of 5 tons to the train.

(*e*) Taking various measurements made on electric tramcars as a standard of comparison, 200 H.-P. will be required to satisfactorily operate a 75-ton train, making an average speed of 20 miles per hour.

Question 2.—What will these motors cost? In giving cost, separate the cost of motors and motor cars.

Answers.—(*a*) Cost of two motors, $5 000, with all regulating devices. Approximate cost of trucks, $3 000, making cost of electric locomotive $8 000.

(*b*) The motor car, body and trucks, without electrical equipment, will cost in the neighborhood of $1 500 to $1 750, depending on weight and finish. The motors would cost roughly $40 per horse-power, to which should be added about $400 per motor car for controlling mechanism, electrical appliances, wiring, labor, etc. Thus, a 150-H.-P. motor car would cost complete about $8 000, although these figures would be somewhat reduced in an actual bid.

(*c*) The Eickemeyer-Field motors will cost about $6 000 for each motor car. This figure includes trucks and ordinary brakes, but does not include air-brake apparatus. The cost of the car bodies will be approximately $4 500 each additional, making the cost of the motor cars, without air-brake apparatus, $10 500 each.

(*d*) The four motors, together with their controlling apparatus, contact trolleys and all other devices necessary to completely equip the car, will cost $5 000 per motor car. The cars themselves we should estimate at $2 000 apiece.

(*e*) No answer.

Question 3.—Give approximate cost of trailers. Cars to be open cars, with cross seats, on first-class double trucks.

Answers.—(*a*) Trailers to be furnished by the Illinois Central Railroad. Cost, about $3 000 each.

(*b*) We cannot at this moment make more than an approximate bid upon the cost of trail cars, as so much depends upon weight, style and finish. The cost would not exceed, however, $2 000, and would probably be a little less.

(*c*) The approximate cost of open trailers with cross-seats on first-class four-wheel double trucks is $3 500 each, with ordinary brakes.

(*d*) The trailers we should estimate at \$2 000 apiece, which ought to furnish a car serviceable, not only for the World's Fair, but for suburban service afterwards.

(*e*) No answer.

Question 4.—Is it desirable to have horse-power used for motor cars consolidated in one unit or divided into two ?

Answers.—(*a*) It is desirable to equip each electric locomotive with two motors.

(*b*) There should be two motors for each motor car. In case one is disabled, the other would be in condition to pull the train in and clear the road without difficulty.

(*c*) It is desirable to have the power divided equally between the two trucks, and applied equally on all the wheels of both trucks, since by this means traction on all wheels will be secured, and in the event of one motor giving out, the other will run the train to the terminal. The motor car can be arranged to drive from either end, the driver's box being placed on one side of the center line of the car, so as to leave the usual free passage from car to car.

(*d*) It will be most desirable to have the motor power divided into two or four parts. The four-part division will give the most efficient means of control, speed and power. This will enable the use of the series-multiple controlling switch, whereby the motors can all be started in series for slow speed and then changed over to multiple series for intermediate speed, and finally thrown into multiple for high speed. A still further adjustment could be made by commuting the fields so that four different speeds, varying from 5 miles to 25 miles an hour, could be obtained with maximum efficiency, and without the efficiency dropping materially at intermediate speeds.

(*e*) With motor cars it is desirable that the horse-power should be divided into two units, the reason being that, in the case of the failure of one motor, the train is not completely disabled. Further, motors of 100 H.-P. would be more satisfactory electrically for varying loads, where the motors are not accessible to the operator. In the present case it is thought advisable to run these two motors in series, so that the electro-motive force on the line can be increased to 1 000 volts. With this electro-motive force, but one-fourth of the weight of copper will be required to transmit the same power as with 500 volts.

Question 5.—What is the best method to transmit the power of the motor to the axle, by gear or by crank ?

Answers.—(*a*) The best method of transmitting the power of the motor to the axle is by placing the armature directly upon the axle, or transmitting it by steel gears.

(*b*) No form of gear or crank transmission should be considered for a moment in work of this character. The armatures should be radial on the axle, and the motors of the utmost simplicity in con-

struction. It is estimated that 75% of the expense of maintaining geared motors is due to the gear in one form or another, not only by direct breakage of gearing, involving the necessity of replacement, but also by armature and field burnouts, due to "locked gearing" or other electrical difficulties, caused by broken parts getting into the revolving parts of the motors. Moreover, there is a constant and heavy drain upon the power station, caused by friction of gearing, which amounts even in comparatively low-speed work to at least 20% of the total power consumption. It is safe to say that motor gearing up to the present time has cost railway companies at least 1¼ cents per car mile on an average. Gearless motors for ordinary street car work have been designed and are now in regular operation at speeds slower than most of the new types of single-reduction motors, and with very high economy in power consumption and cost of maintenance. It is, of course, a much simpler problem to design gearless motors of larger power to run at higher speed and with a greater space at command obtained by the use of a 42-in. wheel instead of 30 and 33 ins. with which the street car gearless motor can be used. The gearless motor has many characteristics which give it great value in all classes of railway work. It starts from rest smoothly, attains speed quickly, and, having no gears to impede, it will bowl along over a smooth track at a cost for power much less than any geared motor. To fulfil your requirements, all that it would be necessary to do would be to increase the dimensions of the street-car motor, making a 33-in. armature instead of a 23-in., as at present, with fields and framework made to correspond. When it is stated that the power of an electric motor varies roughly as the cube of its armature diameter, all other things being increased proportionately, you will see what a simple problem it is to obtain the requisite horse-power in the way above suggested. In mounting these motors on the truck the armature will be keyed to a hollow shaft which will surround the car axle, leaving an annular space of at least 1½ ins. This hollow shaft will be carried in the frame work of the motor itself, hung on strong cross-girders of the truck through flexible rubber bushings of special design. The entire truck frame and motors will thus have an easy spring movement, which will prevent pounding on the track, breakage of wires, etc., which is always found in geared motors which are more or less rigidly attached to the framework. The armature is of the ring type, which permits of separate and independent coils, which may be rewound, in case of burnout, at nominal expense. This peculiar type of armature construction has been found by far the most satisfactory in street car practice, it being adopted by nearly every company. This company was the first to recommend its use, and the road operating it in Rochester, N. Y., is now making 250 000 car-miles per month, at a cost for repairs of less than ½ cent per car mile, although the motors are

of the double-reduction (four-gear) type. Further information upon the peculiarities of the gearless motor will be given verbally or upon request.

(*c*) The best method of transmitting the power of the motor to the axle is by cranks and parallel rods; this calls for a motor which turns its armature at the same speed of rotation as car axle. At first sight, this comparatively slow armature speed might appear objectionable, but it has been found easily possible in practice to so design and construct a motor that under these conditions it will surpass in commercial efficiency any form of motor as yet applied to work of this character. As bearing out our statement that cranks and parallel rods are the best means of connecting the motor to the axle, we have only to point to the engineering practice with steam locomotives for the past 40 years. Again, in mine hoisting machinery, gearing has been almost entirely abandoned, the engines being connected directly to the cable drum.

(*d*) In case only 25 miles an hour is desired, the best method would be by the use of spur gearing—gearing the armature directly to the axle. This will enable the use of standard motors of light weight and render repairs easy. The gears, being single reduction and run in oil, will be practically noiseless, and the wear and tear will be very slight.

(*e*) The best method of transmitting the power to the axle which we are familiar with is the spur gear. Cranks have been used from time to time for this purpose, but the information we have gathered on this subject has not been favorable to the use of these cranks.

Question 6.—What parts of motors are liable to give the most trouble from breakages, and what is the best and quickest method of handling motors that are disabled out on the line, and to avoid the least delays to traffic?

Answers.—(*a*) By using best standard motors there will be no trouble from breakage. In case one motor should be disabled electrically, the train may be run into the terminal station with the other motor and then be repaired.

(*b*) The most trouble from breakage is experienced with gears, which is obviated in the motor described in Answer 5. There is also some liability to burn out armature and field coils in electric motors, if heavily overloaded; but with the type of motor referred to, these burnouts are of very rare occurrence, because of the independence of the armature coils and the fact that they are thoroughly ventilated. Moreover, the burnout of more than one coil at a time is a very rare occurrence, and the motor will do work and help to carry the train through to the terminus, even if several coils are burned out, a very important feature. However, in general plan outlined as above, there is ample power in one motor to draw a train in, so that complete stalling of the train on the road would be very rarely experienced.

(*c*) The parts of motors most liable to give trouble by breakage are the armature and the commutator. This is not saying that these parts are very liable to give trouble, but simply that they are the most liable. The best and quickest way of handling motors that become disabled out on the line is, in case both motors are disabled, to push the train in by the next motor coming along, which, owing to its allowance for development of extra power, should do the work without injury to it. In case but one motor of the car should be disabled, the remaining motor would run the train to the terminus, where it could be exchanged for one of the reserve motors. In the event of such damage to a motor that its shaft would not revolve, the connecting rods could be quickly removed, and the wheels and axles would then serve as an ordinary truck.

(*d*) The parts of the motor most liable to require repairs are the bearings and gears, but these have been so perfected in the last year that their maintenance is about as small as any piece of mechanism could be expected to be. Duplicate trolley wires, duplicate trolleys, duplicate motors and proper cut-out switches will enable a motor car disabled in any of its parts to complete its round trip in any conceivable case. Should, however, such a breakdown occur as cannot be foreseen, and the motor car be completely disabled, it would have to be pushed to the terminal station or to the nearest siding by the train in the rear, and the motors would have abundant power to handle two trains if necessary.

(*e*) With proper system of inspection, there is very small liability of the breaking of any part. The gears require replacing oftener than other parts, but a mechanic should be able to tell from the condition of the gears how much longer they are to be relied upon. The brushes on the commutator would require attention about as frequently as the journals. With proper care these very rarely cause trouble. In case a motor car becomes completely disabled, the best method of avoiding delay would be to side-track the train. One or two motor cars could be held in readiness along the line, so that no serious delay would be possible.

Question 7.—What is the best-known brake for electric cars and motors suitable to the requirements of this line?

Answers—(*a*) The best-known brake for electric railway trains is the Westinghouse air brake. The air pump can be operated by a small separate motor on the locomotive, and all the air-brake appliances will be practically the same as those now in use on steam roads.

(*b*) You should use a Westinghouse air brake of the usual description. We would place in the motor car a small electric motor, geared to an air pump, which would furnish the required power for working the brakes. You would thus have the best working power found in any system of street railway locomotion.

(*c*) The best brake for motor cars and trailers operated in a train, as required, is the air brake.

(*d*) A compression air brake would be the most reliable to use in connection with a system of this kind, the air pump to be operated by a separate electric motor on the motor car and controlled by the driver.

(*e*) The best brake for practice of this sort is the air brake.

Question 8.—What is the largest motor now manufactured, and where is it operated?

Answers—(*a*) The largest motors which this company has constructed for suburban railway service are of 30-H.-P. capacity and are in operation in Sioux City, Ia.

(*b*) We have built 100-H.-P. motors for transmission of power purposes, and dynamos up to 500 H.-P., any of which could be used as motors of the same power on occasion. For railway work, the largest motors yet manufactured in this country are 30-H.-P. motors, which are being put out by the various electrical manufacturing companies, ourselves among the number. In England, the London and South Western Company is using large motors of the gearless type for the operation of their cars under ground, these cars being, as we understand, of the long double-truck type, similar to those which you will require.

(*c*) The largest motors of the type recommended, now in use, are of 30 H.-P., and are capable of developing 50 H.-P. for short periods of time with higher efficiency, and without injury to any part of the motor. Those 30-H.-P. motors are in operation at Toledo, O. They are each mounted on a four-wheel truck of 4-ft. 8½-in. gauge, having a wheel base of 6 ft. The wheels are 26 ins. in diameter, and make 265 revolutions when the car is going 20 miles an hour, which speed is frequently attained. These motors, with trucks complete, weigh 4½ tons, and upon each is mounted a 16-ft. street car body, weighing 3 tons, making the total weight of the motor car complete, 7½ tons. Fifty passengers can be carried in one of these cars without straining or overloading the motor. Curves of 32-ft. radius are rounded without difficulty, and, owing to the small diameter of the drivers, the tendency to leave the track on curves is very slight. In Boston, a 40-ft. car propelled by two 20-H.-P. motors, each mounted on a four-wheel swivel truck, is in use, the motors and method of connection being the same as herein recommended.

(*d*) The largest motor in existence is the freight locomotive at Whitinsville, Mass., rated at 120 H.-P., but which has given an actual draw-bar pull of 10 000 lbs.

(*e*) The largest stationary motor in operation is the 100-K.-W. motor, manufactured by the Edison General Electric Company. This motor is in operation in the Schenectady works and in various other

plants. The largest motor outfit with which we are familiar is the 60-H.-P. equipment manufactured by the Edison General Electric Company. This is in operation upon the Schenectady Street Railway and various other railways.

Question 9.—In using two motors on a car it was understood that the motors work separately on both forward and rear trucks, and that the motor cars do not have to be turned at end of line.

Answers.—(*a*) Using two motors on each locomotive, the train can be operated the same as with steam-power.

(*b*) See answer to Question 10, which is for Questions 9 and 10.

(*c*) The two motors, thus applied to the car, will each work independently of the other end upon its own truck. The motor cars can be driven from either end and in either direction.

(*d*) The four motors would all work in unison, but any one or more could be cut out and the other motors do the work. Motors can be run either way and reversed with a single switch. Each can be controlled from either end of the motor car, and the car can be treated in every respect as a double-ended locomotive.

(*e*) The statement made that the motors do not have to be turned at end of line is correct.

Question 10.—Can both motors be used at once in the same direction, and can motors be reversed on line in an opposite direction, and can both motors be operated from same end of car?

Answers.—(*a*) Both motors can be used at once in the same direction, and may be reversed on the line in an opposite direction, and both motors may be operated independently of each other. With one motor in operation, the speed of the train will be considerably less than 25 miles per hour.

(*b*) Both motors can be controlled from either end of the car to work together in either direction; in other words, you can do with them precisely what you can with a locomotive, and, in addition, you can never speak of the motor car as running backwards, as it is symmetrical in form.

(*c*) Both motors can be used at once in the same direction and can be reversed on line from either end of car. Both motors can, of course, be operated from same end of car.

(*d*) Unless a motor is disabled, all the motors will be used simultaneously, as this gives the most efficient service and least heating of motors.

(*e*) Both motors can be used at once in the same direction. The motors can be reversed on the line in an opposite direction, and both motors can be operated from the same end of the car. The above conditions are common to street railway practice.

Question 11.—If the motor is designed for a speed of 20 miles an hour, with a certain load, can the speed be increased with a less load

without overstraining the motor and without any change in the mechanism, and what percentage can speed be increased?

Answers.—(*a*) The motors will be so designed that when hauling a load of 150 tons they will run at a speed of, say, 25 miles per hour, and with a less load they will run faster without overstraining and without any change in mechanism. The speed will increase nearly in direct proportion as the load decreases.

(*b*) The answer to this question depends upon the characteristic curves of the motor. In a general way, it may be said that we can design and build a gearless motor car which would operate about as follows: In starting a 70-ton train, it would take, perhaps, 125 E. H.-P. During the period of acceleration up to a speed of 20 miles per hour, the power would gradually fall from 125 H.-P. to, perhaps, 50 to 60 H.-P., or even less, the power exerted being required in overcoming friction of journals, etc. With a 50-ton train, the speed would, perhaps, reach 22 to 25 miles per hour, or a slightly greater speed than that of the 70-ton train, but it is a peculiarity of our special method of building motors than the speed under heavy loads does not fall greatly over that required for light loads; in other words, the motors "stand up to their work" on grades or heavy tractive pull. It may be said in passing that it would not be feasible to run a geared motor as rapidly as a gearless, since the liability of breakage would be much greater.

(*c*) Motor cars can readily be constructed so that while adapted for a speed of 20 miles an hour, with a certain load, their speed may be increased to 25 or 30 miles an hour with less load. The speed may even be increased with the same load without overstraining the motor and without a change in the mechanism.

(*d*) The motors designed to run 20 to 25 miles an hour would not be able to go over 35 miles an hour on the level with a light load.

(*e*) If the motor is designed for a speed of 20 miles an hour with a certain load, the speed can be increased with a less load without straining the motors and without any change in the mechanism. It is safe to say the speed can be increased 50% and not exceed the ordinary conditions of good practice.

Question 12.—In how short a distance can trains described above be brought to a stop with existing brakes from a speed of 20 miles per hour?

Answers.—(*a*) The train may be brought to a standstill by the Westinghouse air brake in about 100 ft.

(*b*) With air brakes only, as described, the result would be the same with electric traction as with steam. There is, however, an additional safeguard in an electric locomotive not possessed to the same degree by a steam locomotive. The motors may be instantly reversed by turning the controlling handle in such a way as to actually turn the wheels backward while the train is going forward, thus accomplish-

ing an extremely quick stop. This, however, is to be applied only in the most extremely urgent necessity, as the results are apt to be disastrous from the enormous amount of power necessarily going through the motor. In ordinary service an 80-ton train can probably be stopped within 400 to 500 ft.

(*c*) With air brakes a train of three cars can be stopped, under ordinary conditions of rail service, from a speed of 20 miles an hour within a distance of 350 ft. without excessive jarring.

(*d*) The theoretical distance for stopping a train going at 20 miles an hour would be about 80 ft., but it would not be safe to count on less than 120 ft. under the most favorable conditions, since the driver cannot always gauge his braking power to his load. Taking in all kinds of conditions and distances, all of 200 ft. should be allowed for stopping from a speed of 20 miles an hour.

(*e*) If brakes are put on each car, and the described conditions indicate that they should be, the train moving 20 miles an hour can be stopped in a distance of 200 ft., with ordinary conditions of track.

Question 13.—Upon the line under consideration, what would be the best location for the power house, taking into consideration that after the World's Fair the line will be extended 7 miles south and that trains will have to stop at suburban stations at intervals of ½ mile?

Answers.—(*a*) The best location for the power station will be the center of the line.

(*b*) The best location for the power house is always as near as possible to the center of the road which it is to serve. Other considerations, however, frequently come in to disturb the best theoretical arrangement. It is important that coal should be delivered directly at the power house without cost of cartage, and, therefore, the station should be located near the railroad track. Moreover, in a plant of this size, it would be high economy to condense, and the question of obtaining a cheap water supply for this purpose should not be overlooked. It is impossible to state, therefore, without a comparative estimate of available sites, what would be the best location, but it may be said in general that in a 15-mile line you can safely work within a radius of 2 or 3 miles from the exact center.

(*c*) The best location for the power house, from considerations of economy in distribution of electrical energy and in cost of copper, would be at the middle of the length of the road; this is true whatever the amount of business or number of stops to be made. This is assuming that only one power house can be used. If the length of the road operated should be extended to 15 miles, with a very heavy traffic, it might become more economical to supply the electrical energy from two power houses than from one, but for a traffic extending over 7 or 8 miles, one power house, located at the middle of the road, would keep the cost within reasonable limits.

(*d*) The best location for the power house would be in the neighborhood of 3 miles from the city terminus, and as near to the middle of the line as possible. For subsequent extensions a suburban station would be built somewhere beyond Jackson Park. The stations would be so large that there would be no loss of economy in having two stations instead of one.

(*e*) It is not possible to give an exact answer to this question without knowing the exact value of real estate at various locations along the line; also, facilities for procuring coal. Neglecting these items, however, and taking into consideration the statements made to us that the traffic on this second 7 miles of track to be built after the World's Fair falls off with the distance from the terminus of the present contemplated road, we would say the station could be most advantageously situated within about 2 miles of the end from which the extension is to be made.

Question 14.—How much power plant would be required to operate from 60 to 70 trains of 65 to 70 tons each at a speed of 20 miles per hour?

Answers. (*a*) The power plant should have an aggregate generating capacity of, at least, 4 800 H.-P.

(*b*) You should plan for a power plant of 10 000 H.-P. to provide a sufficient margin for reserve and contingencies. Your average output should not exceed 6 000 H.-P., if you ran three car trains, but there will frequently be call for 7 500 H.-P. on special days when loads or conditions of track are severe.

(*c*) The power plant necessary to operate 60 to 70 trains at 20 miles an hour we estimate at 5 000 H.-P. capacity. This estimate is based on use of 1 000 watts electrical energy for each ton weight to be moved; practically, it would be found that with 60 trains running at 20 miles per hour the horse-power required at the house would fall below 4 000.

(*d*) To operate the above-described four-car train of 100 tons would require about 100 H.-P. in the engine, and, as 40 of these will be running at once, 4 000 H.-P. will be needed continuously during the hours of maximum travel; allowing a reserve of 20%, the total power required for the central station would be 5 000 H.-P.

(*e*) Basing our answer to this question on the present street railway practice, from 12 000 to 15 000 H.-P. will be required to operate from 60 to 70 trains of from 65 to 70 tons at a speed of 20 miles an hour. It is possible that in the present case less power would be required, owing to favorable conditions of track and the small number of stops to be made. We do not feel safe, however, in stating that a less power would be required until we have had an opportunity to make a thorough investigation of the whole matter.

Question 15.—What excess power will be required in such a plant, if any?

Answers.—(*a*) It is advisable that spare machinery of at least 8 000 H.-P. generating capacity be added.

(*b*) You will see from Answer 14 that we allow 25% reserve.

(*c*) No excess of power above 5 000 H.-P. would be required, provided the power units were not too large.

(*d*) Twenty per cent. reserve would be sufficient, provided the station is carefully installed and the apparatus of liberal capacity.

(*e*) In a plant of the present description it seems unnecessary that more than a 20% margin should be allowed. In street railway practice larger margins are generally allowed, but the demands for power in this case are liable to fluctuate very greatly, while in the present case the demand for power is nearly constant.

Question 16.—What would you recommend as to the proper units into which this power should be divided?

Answers.—(*a*) The smallest unit into which it would be advisable to divide this power would be 800 H.-P.

(*b*) We would recommend 1 000-H.-P. engine units and 500-H.-P. dynamo units, two dynamos being coupled direct to the shafts of each engine.

(*c*) We would recommend the division of power into twelve engines of 400 H.-P. each.

(*d*) The units could be either ten of 500 H.-P. each, or five of 1 000 H.-P. each. The former would give greater flexibility, and the latter greater simplicity. It would be a matter that should be decided largely by prices of engines and similar considerations that would come up during the further discussion of the problem.

(*e*) We would recommend as the proper unit of power for the above work 1 500-H.-P. engines and 750-H.-P. dynamos, two dynamos to each engine, the engines to be triple compound condensing, with Corliss valves.

Question 17.—If the requirements for power should be reduced 50% after the World's Fair, what power of each unit would you recommend?

Answers.—(*a*) Answer contained in Answer 16.

(*b*) The same as indicated in Answer 16.

(*c*) If the power plant should be reduced 50% after the World's Fair, we would still recommend the same units of 400 H.-P.

(*d*) In case the power plant was to be materially reduced, the smaller unit of 500 H.-P. would be preferable.

(*e*) We would recommend the same type of machine, if the power should be reduced 50% after the World's Fair.

Question 18.—How many square feet in space will be required for the erection of steam and electric power plant, including boiler house?

Answers.—(*a*) The number of square feet required for the erection of the steam and electric plant, including the boiler house, will be 75 000.

(*b*) You will require a lot of about 350 ft. by 125 ft., or the equivalent in area, in case you can purchase land cheaply; otherwise, it is possible to arrange a two-story building, with a little more than one-half this space.

(*c*) We estimate the space required in square feet for the erection of steam and electric power plant, including boiler houses, at from 15 000 to 25 000, according to types of boilers, engines and generators used, with everything on one floor; if two floors are used, the space required can be reduced to about 12 000 sq. ft., or even somewhat less, if necessary.

(*d*) The boilers will require $2\frac{1}{2}$ sq. ft. per horse-power, or, say, a building 145 x 85 ft., and the engines and dynamos will require 2.61 sq. ft. per horse-power, or, say, a building 145 x 90 ft; so that a building 145 x 175 ft. would be sufficient for the whole power plant.

(*e*) About 27 000 sq. ft. will be required for the erection of steam and power plant, including boiler-house, and a room about 130 x 130 ft. for engines and dynamos, pumps, etc., and a room about 80 x 130 ft. for boilers. We would recommend two separate smokestacks, one on each side of the room.

Question 19.—Give your opinion as to the most economical and best kind of boilers, engines and generators to use for such a plant.

Answers. (*a*) In our opinion, the most economical and best boilers are the Babcock & Wilcox; engines, of the Corliss type, and generators, manufactured by the Westinghouse Electric Company.

(*b*) We would recommend large water-tube boilers with mechanical stokers; a high grade Corliss type of engine and slow-speed generators adapted for direct coupling to the engine shafts. It is unsafe to experiment with new or unusual types of boilers or engines, and nothing but what have been found in the past to be the most reliable under all conditions should be thought of.

(*c*) A water-tube boiler of Babcock & Wilcox or similar design we should consider most economical and best suited to your requirements. For engines, compound condensing, medium-speed engines, directly connected to generator, will give economical results, provided water for condensing can be obtained with little cost. The obtaining of water would depend on the location of the plant. The generators should be of 400 H.-P. each and operated at a voltage of 500 to 600. They can be either of bipolar or multipolar construction and should have a commercial efficiency of 80% or over when under full load.

(*d*) Babcock & Wilcox boilers should be preferred, and compound or triple-expansion engines of slow-speed type, with generators directly coupled to the same.

(*e*) We recommend the Climax type of boiler as the most efficient, economical and as requiring the least floor space. We recommend a vertical triple-compound condensing Corliss-gear engine, with

a sub-base plate or foundation box, on which would be erected the engines and generators, with two generators to each engine, one at either end of crank shaft, with armature coupled directly on the crank shaft. We recommend a multipolar type of generator.

Question 20.—Give approximate cost of power plant, to erect engines, boilers, generators, separately.

Answers. (*a*) The approximate cost of power plant, complete, ready to run, will be $475 000, not including real estate.

(*b*) The steam plant, complete, including engines, boilers, condensers, heaters and all accessory apparatus, together with piping, labor in erecting and everything necessary to make the plant ready for operation, will cost, in round numbers, $60 per horse-power. The electric plant, complete, including generators, switchboard, appliances, controlling apparatus and accessory apparatus, including labor in erecting and making ready for operation, would cost, in round figures, $40 per horse-power. The cost of the power station, complete, would therefore be, roughly, $1 000 000; this figure would easily cover also the cost of the building itself.

(*c*) We estimate the approximate cost of engines and boilers, erected, including necessary pumps and heaters, at $40 per horse-power. This would make a total cost of $200 000 for 3 000 H.-P. The cost of twelve generators erected would be $120 000.

(*d*) The power plant would cost $91 per horse-power, if constructed in a first-class manner. This figure will allow for slow-speed directly coupled dynamos and slow-speed compound engines of the most approved type, and boilers, furnaces, steam connections, pumps, condensers and economizers, all of the best and most reliable makes. It would also include the cost of building, for which an allowance of $10 per horse-power has been made. The dynamos have been estimated at $35 per horse-power and the steam plant at $46 per horse-power, and it is with the understanding that the plant is to be in every way ample and above actual rated capacity that the above figures are given.

(*e*) The approximate estimated cost of the twelve 1 500-H.-P. triple-compound engines, with two dynamos each, would be $1 000 000. The approximate estimated cost of the boilers would be $144 000, and the necessary piping, pumps, etc., to the amount of about $20 000 to $25 000.

Question 21.—Give estimated cost for operating power plant, with coal at $1 per ton.

Answers.—(*a*) We estimate that the cost of operating the power plant, with coal at $1 per ton, will be $60 000 per year, including all fuel, labor and repairs.

(*b*) It would be entirely safe to figure upon $30 per horse-power per year in a station of this size, operating for 18 hours a day. The cost of generating, therefore, 7 500 H.-P. would be $225 000 per year, which should cover all expenses.

(*c*) When running at full capacity, the cost of fuel per hour, with coal at $1 a ton, would be about $4. This gives 2 lbs. of coal per horse-power per hour. The expense for firemen, engineers, generator attendants, we estimate at about $4 per hour. This would allow ten firemen at $2 each per day; two engineers at $5 each per day; one head generator attendant at $5 per day, with two assistants at $2 50 each per day.

(*d*) In the following estimate the interest and depreciation are included so as to enable the railway company to make a ready comparison between the electrical system and the steam system. No account is taken of the maintenance of cars, trucks, roadbed, etc., as these are believed to be common to both systems, with a slight advantage in favor of electricity, because of its greater cleanliness and greater ease on the roadbed.

CENTRAL POWER STATION.

Capacity, 5 000 H.-P.; maximum duty, 4 000 H.-P.; reserve, 1 000 H.-P.

Initial Cost:	Total.	Per H.-P.
Boilers and Furnaces, 10 Babcock & Wilcox (500 H.-P. each)	$75 000	$15
Piping, pumps, heaters and all accessories	25 000	5
Engines; five compound condensing, 1 000 H.-P. each	100 000	20
Foundations	30 000	6
Steam plant complete	$230 000	$46
Building	50 000	10
Dynamos 5 000 H.-P., each to be direct coupled compound wound and to develop 800 volts; with switchboard and all accessories	175 000	35
Power station complete ready to run	$455 000	$91

	Per day.	Per H.-P. hr.
Interest on power station, at 6% per annum, $27 300	$74 80	
Maintenance and Taxes, at 5%	62 30	
Operating Expenses:		
Coal, 48 000 H.-P.-hours per day, at $1 per net ton, and 3 lbs. per H.-P.-hour.	$72 00	$5.001500
Oil and waste	2 16	.000045
Engineers, 2 at $4	8 00	.000167
Oilers, 4 at $2	8 00	.000167
Firemen, 8 at $2	16 00	.000334
Dynamo men, 2 at $3	6 00	.000125
Superintendents, 2 at $6 and $10	16 00	.000334
Total wages	$54 00	

Total cost of operation for six hours maximum work, and twelve hours at 50%, 48 000 H.-P.-hours, and 480 train-hours, or 9 600 train-miles, or 38 400 car-miles per day..................	$265 19

Total operating expenses per H.-P..hour.............	$0.00553
" " train-mile..............	.0276
" " car-mile................	.0069
" " passenger-mile, assuming that the cars carry 50% of their seating capacity..	.000123

Cost: LINE.

7½ miles of center-pole construction, including four lines of trolley wire and insulated feeders, sufficient to give a maximum drop of 20%, all complete..	$40 000 00
Block signal system for automatically stopping trains approaching within a given distance of preceding trains....	12 000 00
	$52 000 00

			Per year.	Per day.
Interest at 6 per cent....................			$3 120 00	$8 54
Maintenance of Line:				
One line foreman, at $2 50	$2 50			
Four line men, at $1 75....	7 00			
Total wages	$9 50			
Supplies.................	1 00			
Total.................	$10 50			
			$10.50	
Running expense of line per day...			19.04	
Running expense of line per train-mile..........................			.002	
Running expense of line per car-mile.........................			.0005	
Running expense of line per passenger-mile.....................			.00000892	

Cost: MOTORS.

Complete electric equipment for 60 motor cars, each including four standard 25-H.-P. single reduction water-proof motors with controlling mechanism and all accessories, including the installing of the same at Chicago and wiring of motor cars, at $5 500 per motor car.........................	$330 000

	Per year.	Per day.
Interest at 6 per cent	$19 800 00	$54 36
Maintenance and taxes, 10 per cent	33 000 00	90 41

Operating Expenses:

60 drivers, 12 hours per day, at $3	$180.00	
Grease and waste	15.00	
Running expense per day		$339 77
" " per train-mile		.0354
" " per car-mile		.0088
" " per passenger-mile		.00016

Assuming average of 50% load.

Total Initial Cost:

Central power station	$455 000 00
Line	52 000 00
Motor equipment	330 000 00
Total	$837 000 00

Motive Power Running Expenses Per Day:

Central power station	$265 19
Line	19 04
Motors	339 77
Total	$624 00

Motive Power Running Expenses Per Train-Mile:

Central power station	$0.0276
Line	.0020
Motors	.0354
Total	$0.0650

Motive Power Running Expenses Per Car-Mile:

Central power station	$0.0069
Line	.0005
Motors	.0038
Total	$0.0162

Motive Power Running Expenses Per Passenger-Mile:

Central power station	$0.000123
Line	.000009
Motors	.000160
Total	$0.000292

(*e*) The estimated cost of operating power plant, with coal at $1 per ton, 12 hours per day, would be as follows :

Coal, 110 tons	$110 00
One chief engineer, at $6 per day	6 00
Four assistant engineers, at $4 50 per day	18 00
One chief electrician, at $3 50 per day	3 50
Eight oilers, at $1 50 per day	12 00
Eight wipers, at $1 25 per day	10 00
Eight dynamo tenders, at $1 50 per day	12 00
Twenty-four firemen, at $2 per day	48 00
Two water tenders, at $1 50 per day	3 00
Twelve coal wheelers, at $1 25 per day	15 00
Ten helpers, at $1 25 per day	12 50
Water, at 1½ cents per 1000 galls.	90 00
Oil, waste, etc.	80 00
Total	$420 00

Question 22.—Will an electrical engineer be required to superintend the operation of this plant, or will a mechanical engineer be able to do so ?

Answers.—(*a*) For the operation of this plant a first-class mechanical engineer having experience in electric railroading, with an electrician for an assistant, will be required.

(*b*) You should engage for your service an engineer of the highest professional standing. He should have a special experience in mechanical engineering, with some knowledge of electricity. He should have as assistants a first-class mechanical engineer, to have charge of the steam plant for the power station; a good electrician, to take charge of dynamos and electrical power plant; a superintendent of motive power or master mechanic, to take charge of car and station repairs of all sorts; and a superintendent of construction, for the overhead wiring system.

(*c*) A competent and experienced mechanical engineer can soon acquire the additional knowledge necessary to fit him for the position of superintendent of this plant. No electrical engineer who did not combine a thorough knowledge of mechanical engineering would be competent to superintend this plant.

(*d*) An electrical engineer, who should also be a mechanical engineer, will be necessary to superintend the operation of the plant.

(*e*) There should be one engineer of each class, as named in estimate in Answer 21.

Question 23.—What is the best method of transmitting power from power house to motors ?

Answers.—(*a*) The best method of transmitting power from the power house to the motors is by the overhead trolley system, which will cost $150 000, including poles and all necessary copper wire.

(*b*) The overhead trolley system.

(*c*) The best method of transmitting power from the power house to the motors is by the overhead trolley system with rail return.

(*d*) The overhead trolley wire is decidedly the preferable means for conveying current to the motors. It would be fed by feeders, which would also be overhead or placed in a conduit.

(*e*) We would recommend as the best method of transmitting power from power house to motors the overhead trolley system.

Question 24.—If by the use of conduit, give estimated cost. If by the three-rail system, give cost. If by the overhead trolley system, give cost.

Answers.—(*a*) Answer contained in Answer 23.

(*b*) We would advise a strong wooden-pole construction on account of cost and insulation. The cost of poles, trolley wire, brackets (for center pole construction, which would probably be the best, if the suburban tracks are side by side), line appliances, track wire and labor in erecting, would be not far from $2 500 to $3 000 per mile of double track. The cost of feed wire would be very large and could not be given without knowing the location of the power station. It will be, approximately, $15 000 to $20 000 per mile of double track for a railroad system 15 miles in length, with power station in the center, operating 50 trains, requiring 100 average horse-power each.

(*c*) We estimate the quantity of copper required for conductors at 500 000 lbs. for the overhead conductors, and 250 000 lbs. for the rail work. At 15 cents a pound for copper this would make $75 000 for the overhead work, and $37 500 for the rail work. Copper is at the present time selling at a little less than this, being lower than it has been for a number of years. The cost of construction and material other than copper for the single line of poles required between the two lines of rails we estimate at about $10 000.

(*d*) The cost of the trolley wire with center-pole construction, together with necessary feeders, cut-out switches, lightning arresters, and all of the necessary apparatus to operate the line efficiently and safely, would be $1 000 per running train. Assuming that 40 trains would be running, it would require $40 000 for line construction.

(*e*) The cost of this overhead system could not be determined until line has been laid out, as the extra service would call for special line material, the style of which could only be determined by taking into consideration all of the conditions to be met.

Question 25.—If the overhead trolley system is used, what is the best method for supporting wire, and how far should the supports be apart?

Answers.—(*a*) The best method of supporting the wires in this particular case is by bracket suspension, and poles should be not more than 125 ft. apart.

(*b*) As before stated, we would advise wooden poles, with side brackets, extending over the side of each track, placed about 100 ft. apart.

(*c*) With overhead trolley system, the best method of supporting wires is by posts set midway between the two lines of rails, these posts being provided with iron bracket arms, extending 18 or 20 ins. on each side of the posts, trolley wire to be supported by proper clamps from the extremities of the bracket arms. Poles should be fifty to the mile, which would bring them about 100 ft. apart.

(*d*) Wooden poles 100 ft. apart placed between the two tracks, with a cross-bar reaching out each way to the center of each track, from the ends of which arms the trolley wires are supported from insulators, would be the preferable method of construction.

(*e*) For the overhead trolley system we would recommend the center-pole construction as being the best for the system under consideration.

Question 26.—(1) What size should trolley wires be? (2) What size should feed wires be, and what distance apart should they feed into the trolley wire? (3) Give probable cost of repairs and maintenance of three systems.

Answers.—(*a*) (1) The trolley wires will be No. 00.

(2) The size of the feed wires to be determined after a more complete examination of the nature of the ground, and they should feed in the trolley wire ½ mile apart.

(3) The overhead trolley system will require practically no outlay for repairs, if put up properly.

(*b*) (1) Trolley wires should be No. 00 or No. 000, B. & S. gauge.

(2) There would be a number of insulated feed wires not exceeding No. 0000 in size. They should feed into the trolley wire at intervals of not over 500 ft.

(3) The overhead system should be maintained at a cost for labor and material of less than 5% of the original cost per year.

(*c*) (1) Trolley wire should be ½ in. in diameter of hard-drawn copper.

(2) Parallel conductors connected to the trolley wires at every post, in circuit with the trolley wires, would be employed, these conductors varying in capacity, according to the current to be conveyed.

(3) The cost to maintain and keep in repair the system of overhead wires and poles would not be very heavy. If properly constructed in the first place, the annual expenditure for maintenance would be a smaller percentage of the cost than that of maintaining a single line of track on the railroad.

(*d*) No. 00 wires should be used for trolley wires and about 60 000 ft. of No. 0000 wires for feeders. They should feed in at sections corresponding with the signal blocks and should be controlled by switches at the central station and also at the line, so that the current could be cut off from any part of the line either automatically by the block signal or at the will of the officials of the road. To repair this overhead system would require a gang of five men; one at $2 50 per day, and four at $1 75, making a total of $9 50 for wages, and $1 for supplies per day, making a total of $10 50 per day for maintenance of line.

(*e*) The size and style of trolley wire will have to be determined after plant is laid out. It is probable that special means for making the trolley contact would have to be provided. Feed wires * * * should feed into the trolley wire about every 500 ft. This distance, however, will have to be determined with reference to the size and style of trolley conductor finally determined upon. We are unable to give cost of repairs on such an overhead system until all the details have been worked out. If properly put in, it should not exceed 3% of the first cost.

Question 27.—What percentage of extra equipment will be needed to provide for repairs?

Answers.—(*a*) We would advise that 10% of the regulating devices for the motors, armatures, field coils, commutators, brush holders, gears and trolleys and bearings be kept in stock for repairs.

(*b*) You would need about 25% in the power station to provide for repairs and contingencies of traffic, and you should provide about 10% reserve of car equipment for repairs only.

(*c*) Ten per cent. extra equipment would be sufficient to provide for repairs.

(*d*) There should be allowed an extra equipment of motors of 10% of the whole number, and it would be necessary to keep in stock about $2 000 worth of duplicate supplies in the shape of gears, brasses, armatures, etc.

(*e*) About 15% extra equipment will be required to provide for repairs. The percentage of extra equipment depends very largely upon the superintendence and care given the motor cars.

Question 28.—What will be necessary in the way of repair shop, plant and forces to repair motors?

Answers.—(*a*) A small repair shop, with the following tools will be required: One hydraulic wheel press for pressing wheels on end of the axles; one engine lathe large enough to take in armature axle for turning down commutator and for repairing armatures in general; four winding lathes for winding armatures, and one lathe for winding field coils, in case you decide to wind your own coils; one small engine lathe for making minor repairs to regulating devices and a few vises

for bench work. The repair shop should also have the necessary soldering tools for repair work. One complete blacksmith shop outfit, one line wagon and line tools, blocks, tackle, etc. Total number of men in repair shop, about six.

(*b*) If you adopt gearless motors and slow-speed generators with ring armatures, you will need a small machine shop, covering an area of perhaps 50 x 30 ft., equipped with a few lathes, two or three planers, a radial drill, etc. Your force would consist of a half-dozen winders, who need not be skilled workmen, four or five good mechanics and a foreman. Your stock would consist of brasses, Babbitt metal, commutators and commutator bars, and three or four sizes of copper wire. The above is on the supposition that the heavy machine repairs on engines, etc., will be done in your locomotive repair shops, and repairs on car bodies and trucks in your car shops.

(*c*) The repair shop will call for an outlay in tools and employment of forces of no more than that necessary for a steam equipment of the same capacity. It is probable that this item of expense will fall considerably below that of a steam plant in the course of several years' operation, but for a year or two it will be safe to place the two systems on a level in this particular.

(*d*) A machine shop for ten mechanics, with ten lathes, one drill and one blacksmith's equipment, would be necessary to keep the motors in repair. There will also be room for a car repair shop for ten motor cars. This will require a space of about 70 x 200 ft.

(*e*) The tools required for repair shop will be about as follows: One 30-in. lathe, one medium-size drill press, one press for pressing commutators off and on, one gear cutter, one milling machine, one complete blacksmith shop, one forge.

The necessary help would be about ten men, at $2 per day, and this repair shop could be looked after by the superintendent of the line, assisted by the chief electrician.

Question 29.—In considering the question of the advisability of running more cars of less weight and capacity, is it desirable to construct a separate electric locomotive carrying no passengers, or a separate motor room in each end of the car, with a limited passenger capacity between the two motors, for the purpose of having larger drive wheels? Or would you recommend the present style of motor? Give prices of the three different kinds of motors.

Answers.—(*a*) In our opinion, it is desirable to construct separate locomotives carrying no passengers. These locomotives to be equipped with two motors each. Diameter of driving wheels to be 42 ins.

(*b*) As before stated, it would not be difficult to build a motor car of the type specified to handle three instead of two double-truck trail cars, all heavily loaded. We would not advise building a separate electric locomotive which would carry no passengers, because of

the fact that the controlling mechanism in electric motor cars is simple, and requires very little room as compared with that of a steam locomotive. Moreover, by making the motor car carry passengers, the weight of the latter is available for traction, and, as this car would be a smoking car, it would nearly always be well filled. We have already indicated the price of passenger motor cars. The price of an electric locomotive would not be greatly different, but would be more, rather than less.

(*c*) We think that it would not be desirable to construct a separate electric locomotive, carrying no passengers, but that the motor car should constitute one of the three passenger cars. We think the advantages lie in favor of trains with three cars, including the motor car, of medium weight and capacity. Two or three trains could be loaded at the same time, and, when loaded, could get under way promptly. No room would be taken up in the motor cars by the motor mechanism, and this car body could be the same in construction and capacity as those of the trailers.

(*d*) We do not think anything would be gained by running more cars of less weight and capacity. The trains could not well be operated nearer together than one a minute, and four-car or five-car trains could be operated about as well on this headway as a two-car or three-car train. Should the line be eventually used for suburban service, with frequent stops, the number of cars per train would have to be reduced, probably to three, while the central station power would remain the same. This is to allow for the greater power required to accelerate after the frequent stops. We would not advise partitioning off part of the motor car, as the whole of it might be utilized for passengers, but there would have to be a vestibule for the driver, in case the cars had no platform. The wheels would be 36 ins. in diameter, so that they would not come within the car body. In regard to the alternative of the separate locomotive, there is to be said—such a motor to do this work would be our 16-ton locomotive * * * equipped with two gearless motors. The cost of this would be $12 000, and it would be able to make greater speed than the gear motor above referred to—40 miles an hour, if necessary. These motors have not yet been built, but are now in process of construction, and would probably operate the road as efficiently as the single-reduction motor. The chief difficulty would be in producing a new type of motor in time for the World's Fair, especially as such a great number of them would be required.

(*e*) We think that your experience in handling passengers should enable you to give a much more accurate estimate of these questions than we are able to make. We are in favor of using motor cars instead of electric locomotives, since in the case of the motor cars the weight of the passengers with the heavy car necessary to carry them is

available for traction. We would also recommend the present style of motor.

Question 30.—How much will it cost to operate this system per mile, per motor and per car, and also per passenger per mile?

Answers.—(*a*) The cost of operating forty 30-ton electric locomotives will be from 9 to 10 cents per mile per locomotive, including all labor and repairs.

(*b*) You can operate at about 12½ cents per car-mile, or 35 cents per train-mile. If the traffic to the World's Fair is as great as is anticipated, you can undoubtedly operate at from 2 to 2½ cents per passenger. We shall be pleased to give detailed and convincing estimates of the cost of operation, if desired, and at the proper time.

(*c*) To figure the cost per mile per motor and per car and also per passenger per mile would involve a considerable amount of calculation. We will make this calculation later and submit it when made.

(*d*) Answered in No. 21.

(*e*) We are unable to give an accurate answer to this question at this time. Various factors enter into this that require considerable time to consider.

Question 31.—Is there any electric line in operation similar to the one under consideration?

Answers.—(*a*) There is a similar line on a smaller scale equipped by the Westinghouse Company now in operation at Sioux City, Ia. On this line, however, the motor car carries passengers. The road has 4% to 5% grades, with sharp curves.

(*b*) Not precisely, but, as before stated, we are meeting conditions in service of street car work which vary only in slight degree from those under consideration.

(*c*) There is no electric line in operation similar to the one under consideration.

(*d*) The line running from Brooklyn to Coney Island operating trains of three cars at a speed of 15 to 20 miles per hour and carrying 250 passengers per train is the nearest approach to the conditions given at Chicago. The West End road in Boston, operating from 300 cars over about 100 miles of line, is also a comparable instance. The West End is now building two large stations, the larger of which will have a capacity of 27 000 H.-P. They are now operating on one circuit about 3 000 H.-P.

(*e*) We are not familiar with any electric line that is similar to the one under construction.

Question 32.—What is the longest line now operated, and the greatest number of cars that are operated with one motor?

Answers.—(*a*) The longest line now in operation with one motor car and three trailers is in Sioux City, Ia.

(*b*) One of the longest lines now operated is probably that between St. Paul and Minneapolis, a distance of about 25 miles; a speed of 20 to 25 miles per hour is attained on this road, we believe. One of the most severe conditions of operation that we know of is found at Jamestown, N. Y., whose street railway is operated by our motors. The motor cars have 18-ft. bodies, exclusive of platforms, which are vestibuled, making a car which weighs, with motors, between 6 and 7 tons, without loads. These cars are equipped with two 15-H.-P. double-reduction motors. The summer traffic is very heavy, and the motor cars draw in regular service one trail car, both heavily loaded, over a succession of grades reaching a maximum of 10% and having a number of sharp reverse curves therein. During the past summer there have been occasions when the railway company has been forced to draw three trail cars with one of these 30-H.-P. motor cars, making four in all, over some of the lighter grades of the road.

(*c*) There are many lines of electric cars, 8 miles in length, in operation at present, and two cars are frequently operated by a single motor car.

(*d*) Accompanying this paper is data sufficient to answer this question. (Answer 31.)

(*e*) The longest line with which we are familiar that is operated from one station is 13 miles in length. We believe there are longer lines, but in general they are operated from more than one station.

Question 33.—Give capacity per hour, speed and time between trains?

Answers.—(*a*) See page 664.

(*b*) We have no information with which to reply to this question.

(*c*) The electric lines now in operation are ordinary street car lines.

(*d*) The greatest traffic handled by an electric road with which we are familiar is the West End, which handles on its electric cars as many as 15 000 passengers per hour. The cars run on some parts of the line with less than 20 seconds headway and are often operated at a speed of 18 miles an hour.

(*e*) A train could be started every minute, and, supposing each train to carry 336 passengers, this would make about 20 000 passengers per hour. To do this, however, would necessitate the construction of three platforms from which passengers could enter cars at both sides at the same time. We would suggest that the train drop its passengers at one platform and then move forward to another platform where passengers could enter cars. By having three platforms from which trains would leave, it would give three minutes for a train to become loaded. The speed on the line could be arranged at anywhere between 20 to 25 miles an hour. The time between trains would be one minute. It would possibly be better to make the road four tracks wide with switches at every half mile, so that in case of accident to a

train the train following could be switched on to the other track for the same direction, and thus avoid delay. The road, of course, would have to be equipped with the block system, or something similar, so that "end on" collisions would be avoided.

Question 34.—Is it possible and practicable to carry from 20 000 to 30 000 passengers per hour with electric power under the conditions named?

Answers.—(*a*) There is not the slightest doubt but that 20 000 to 30 000 passengers can be carried from the Lake Front Park, in the city of Chicago, to the Columbian Exposition by electric power under the above conditions.

(*b*) Yes, without question.

(*c*) We think it possible and practicable to carry 20 000 passengers per hour, or more, from Lake Street to Jackson Park by electric power under the conditions named. First-class terminal facilities would need to be provided in order to reach the above figure.

(*d*) It is quite possible and practicable to carry 20 000 and, probably, 30 000 passengers per hour with the electric motors under the conditions named.

(*e*) The statements made in Answer 33 apply as well in this.

Question 35.—Is it possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893?

Answers.—(*a*) It is possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893.

(*b*) Yes. We could install three such plants with our present factory facilities.

(*c*) We consider it possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893.

(*d*) It is quite possible and practicable to have the plant in operation by March 1st, 1893, especially if standard motors are used and the contract given before April 1st, 1892.

(*e*) We think it possible and practical to supply the apparatus for this plant, ready for full and complete operation, by March 1st, 1893.

Question 36.—How soon will it be necessary to award the contract for the above plant in order to have the line ready for operation by March 1st, 1893?

Answers.—(*a*) It will be necessary to award the contract for the above plant on or before March 1st, 1892, in order to have it in operation by March 1st, 1893.

(*b*) The contract should be placed by March 1st, 1892, in order to be certain of completion at the specific time.

(*c*) In order to complete this plant by March 1st, 1893, contracts for the principal portions of the work should be made very soon.

(*d*) Before April 1st, 1892.

(*e*) It would be necessary to award the contract at the earliest possible date, not later than March 1st, 1892, since the apparatus should be put in operation by installments, and the various officers become familiar with their duties before the system is worked to its full capacity.

Question 37.—Would your company guarantee, on your own specifications and at an agreed price, the successful installation and operation of this plant by March 1st, 1893, with guaranteed capacity of 20 000 people per hour in one direction? (It is understood that whenever the capacity of 20 000 people per hour is mentioned, it is in one direction.)

Answers.—(*a*) Yes; provided you make the necessary arrangements to load the passengers on and off the cars.

(*b*) We would make such a guarantee under heavy penalties of non-fulfilment.

(*c*) In our opinion, the units above indicated, that is, an engine, with boilers and generator and one train of cars, could be placed in operation by June 1st, this year. This train could be operated over a sufficient length of your track to fully determine all questions of speed, power and capacity. Our company would probably be willing to undertake the construction of the electrical apparatus required within the time specified, conditioned on the approval of the operation of the single train, above mentioned, at as early a date as practicable. Our preference would be not to have the responsibility of the contract for the steam plant, nor for the erection of the conducting wires; there are parties who make this line of work specialties, and if we were called upon to assume the whole contract, we should employ such parties to do such portions of the work.

(*d*) Yes.

(*e*) No answer.

Question 38.—Do you recommend horizontal or upright engines?

Answers.—(*a*) We recommend engines of the Corliss type.

(*b*) With more time in which to act we would probably be willing to recommend vertical engines, but they have not yet stood the test of as long experience as have horizontal engines, and, as it is most important that experimental work be avoided, we recommend horizontal Corliss engines, as stated above.

(*c*) Our preference would be for horizonal engines.

) No answer.

e) We would recommend vertical engines, as before stated.

Question 39.—What is the best form of connection between engines and generators, belt or countershaft?

Answers.—(*a*) In our opinion, the best forms of connection between the engine and dynamo are ropes or belts, doing away with all countershafting.

(*b*) Both should be avoided and direct connection made between the dynamos and engines. In the latest and most improved engineering practice very slow-speed dynamos have been developed, corresponding to the speed of the engine used. If it is necessary to use transmission by either belt or countershaft, belts should be employed without question. Countershafts should be avoided under all circumstances.

(*c*) Our preference would be for direct connection between the engine and generator, not using either belt or countershaft.

(*d*) No answer.

(*e*) We would recommend direct-driven dynamos without belt or countershaft.

Question 40.—Are high or low speeds preferable, and about how many revolutions per minute?

Answers.—(*a*) Low speeds are preferable—300 revolutions per minute.

(*b*) Low speeds—about 100 revolutions per minute.

(*c*) Our preference would be for a medium speed, say 90 to 100 revolutions per minute.

(*d*) No answer.

(*e*) We would consider moderately high-speed engines preferable. In the engines before mentioned the speed would be 100 revolutions per minute, with a piston speed of 600 ft. per minute.

Question 41.—What is the proper size of wheels for motors and for trailers?

Answers.—(*a*) The proper size of wheel for the locomotive is 42 ins., and for the trailers the same as now on the suburban cars—33 ins. diameter.

(*b*) For motor cars, 42-in. wheels; for trail cars, bogie trucks, 36-in. wheels.

(*c*) We should say that the size of the car wheels on motors and trailers should be about 30 ins. diameter.

(*d*) No answer.

(*e*) We would recommend for the proper size of wheels 48 ins. for motor cars and trailers.

Question 42.—What will be the percentage of loss in power between the steam engine and the motor ?

Answers.—(*a*) The efficiency of the system will be as follows: Efficiency of engine, 85%; efficiency of dynamos, 94%; efficiency of line, 80%; efficiency of motors, 90 per cent.

(*b*) Between the cylinder of the engine and the pulley of the dynamo there will be a loss from engine friction of about 15 to 20 per cent. There will be a total loss in the dynamo of about 6% in a 500-H.-P. generator, and an average loss between the station and the motors of about 15 per cent. There will be an average loss of about 20% in

the motors. The general efficiency of the system will, therefore, be slightly over 50 per cent.

(c) The percentage of loss in power between the steam engine and motor will be about 25%, to which must be added the loss in the motor itself of about 15 per cent. The total loss of energy between the shaft of the engine and the rails will probably approximate 50 per cent.

(d) No answer.

(e) The approximate loss between the steam engine and motor would be about 15 per cent. This is about equally divided between the dynamos and line.

Question 43.—What is the lowest practicable radius for curves in terminal loops ?

Answers.—(a) The curves on the terminal loop should not be less than 100 ft. radius.

(b) There will be power in the motors sufficient to carry a three-car train around a 50-ft. circle, and there will be no mechanical difficulties in the way. It is, of course, desirable to have a much larger circle, up to 200 or 300 ft.

(c) We think the radius of curves in the terminal loops should not be less than 100 ft., and, of course, it would be better to have the curves of a still greater radius than that.

(d) No answer.

(e) We think your experience would be a surer guide as to the best practice in the matter of curves, but would suggest, however, that the curves be not less than 150 ft. in radius.

Question 44.—What radius of curvature on the loops, on the supposition that the trains will be empty in going around the loops, and run at a speed of about 5 miles an hour, will make the resistance on the loops equivalent to a speed of about 20 miles an hour on the straight portion of the line ?

Answers.—(a) Curves with a radius of about 100 ft.

(b) No answer.

(c) We have no sufficient data for estimating what curvature on the loops would make the resistance on the loops equivalent to a speed of 20 miles an hour on the straight portion of the line.

(d) No answer.

(e) The answer to this question depends upon such a number of variables that we are unable to give an accurate answer. Under ordinary conditions of road this varies considerably with the speed the train had when it took the curve, and the rate of acceleration on the curve.

Question 45.—Can air be applied to closing and opening side car doors on passenger trains?

Answers.—(a) No answer.

(b) Yes, if desired, but, as before stated, we would strongly advise end entrances for this class of travel.

(*c*) We do not feel qualified, without taking further time for investigation, to pass on the question as to the best method of opening and closing the side car doors on passenger trains. We know of no reason, however, why air could not be applied to the opening and closing of these doors.

(*d*) No answer.

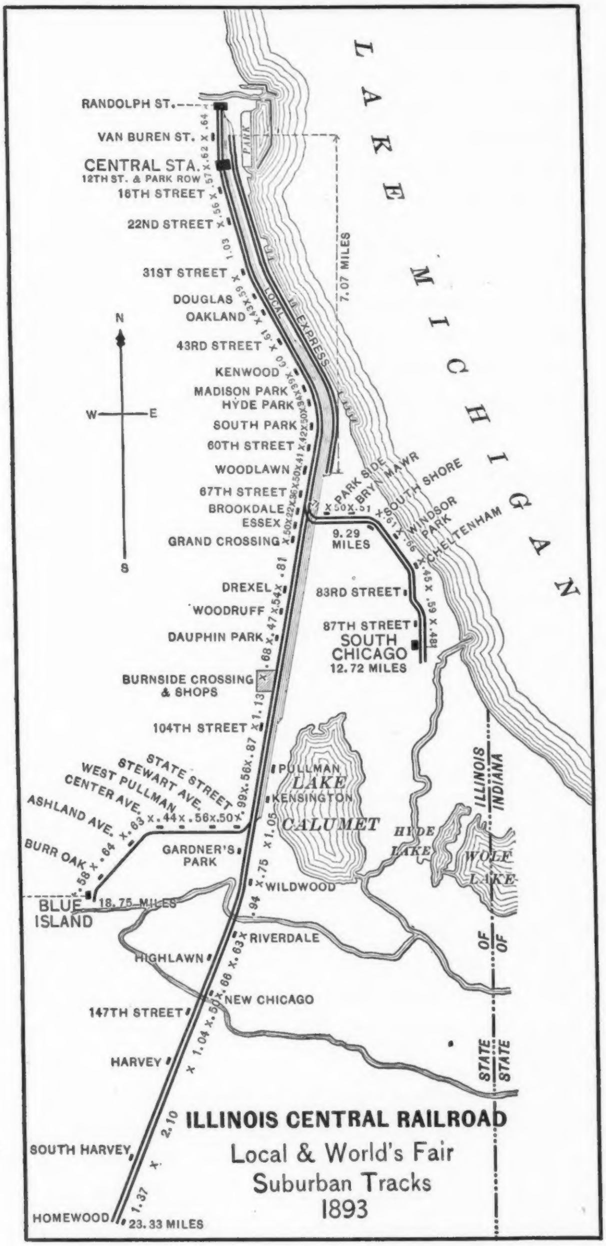
(*e*) Air may be readily applied to open and close the side doors of passenger trains, but we would consider this would be objectionable in trains moving at such a high rate of speed, as passengers would hardly become seated before the train left the station, and with an automatic arrangement of this kind there would, no doubt, be considerable injury to the passengers from the doors catching their clothing and limbs.

In addition the author personally visited the works of various electric manufacturing companies in the United States, and also discussed at length the different phases of the problem with electric and mechanical experts. The answers to the preceding questions were furnished after careful and mature deliberation on the part of the electric companies.

In order to illustrate the situation as to track arrangements, Fig. 1 shows the lay-out of the tracks used exclusively by the Illinois Central Railroad for its suburban service, with its different suburban stations. The two heavy black lines on the left of the diagram indicate the two tracks set apart for the exclusive World's Fair business, and the remaining heavy lines show the tracks devoted to the regular suburban service.

In regard to the practicability of handling a large number of people by electric power between the site of the Exposition and Van Buren Street, in the city of Chicago, the author was satisfied it was both possible and practicable to handle as large a number as 20 000 persons per hour between the points mentioned by electric power. He was also satisfied that it was possible and practicable to handle the entire suburban business of the Illinois Central Railroad between Randolph Street and Homewood, South Chicago and Blue Island by electric motive power.

While it would seem in a general way to be self-evident that it would be more economical to generate power at a central station and transmit it to motors by electricity, than to maintain and operate separate and distinct steam plants (locomotives) to propel each individual transportation unit, the practical results so far obtained from a com-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OAKLAND
43RD STREET
KENWOOD
MADISON PARK
HYDE PARK
SOUTH PARK
60TH STREET
WOODLAWN
67TH STREET
BROOKDALE
ESSEX
GRAND CROSSING
DREXEL
WOODRUFF
DAUPHIN PARK
BURNSIDE CROSSING & SHOPS
104TH STREET
PULLMAN
KENSINGTON
LAKE CALUMET
STATE STREET
STEWART AVE.
WEST PULLMAN
CENTER AVE.
ASHLAND AVE.
BURR OAK
GARDNER'S PARK
BLUE ISLAND
18.75 MILES
WILDWOOD
RIVERDALE
HIGHLAWN
NEW CHICAGO
147TH STREET
HARVEY
SOUTH HARVEY
HOMEWOOD
23.33 MILES
LOCAL
EXPRESS
PARK
7.07 MILES
PARK SIDE
BRYN MAWR
SOUTH SHORE
WINDSOR PARK
CHELTENHAM
9.29 MILES
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Local & World's Fair
Suburban Tracks
1893

Fig. 1.

parison of the cost of operating steam power as applied to steam railroads, and the use of electric power as applied to street car lines, does not bear out the theory. This, however, may be partially accounted for as follows:

In the application of electricity as a motive power, which has only been in use for a few years, and then only to operate street car lines, the engineers giving this matter their attention have been enthusiastic electricians; they have seldom been practical or expert mechanics.

Electricity as a motive power has only been used under the most unfavorable conditions, to operate street car lines with crude motors, poor track complicated with sharp curvature, steep grades and operated by comparatively inexperienced and inefficient men, mule-drivers having frequently been converted into electric motormen.

In considering the present problem, however, the application would be made on first-class standard gauge track, with practically no grade and very slight curvature, except at terminal points; stops would be infrequent, the most improved motors would be used and placed in charge of intelligent and disciplined men, rendering the conditions under which the electric power would be used the most favorable that have ever existed. There was, at the date of this examination, no electric line operated under such favorable conditions with which comparisons could be made, consequently no estimate of the cost of operating an electric system under these conditions could be made more than approximately. In the then existing electric street railway practice operating expenses amounted to 2 to $3\frac{1}{2}$ cents per passenger carried. This was a very favorable showing, however, considering the unfavorable conditions—the use of geared motors, bad roadbed, inefficient management, and the fact that all street railway lines ran large numbers of cars containing but few passengers, some of the larger systems having non-paying branches upon which traffic was very light, which had a tendency to increase the cost per passenger.

There were also several considerations in favor of the adoption of electric power which could not be reduced to dollars and cents, viz.:

First.—The ability to run more transportation units in the suburban service at less expense per unit, than by the use of steam, thereby changing the present steam suburban service from a time

card to a street car basis, doing away with the necessity of passengers waiting for schedule trains and thereby building up and increasing the suburban service.

Second.—The advantage of not being required to stop for coal and water.

Third.—The absence of smoke and dirt.

Fourth.—The possibility of the road being required to use anthracite coal for engines inside the city limits of Chicago, increasing the cost of fuel at least five-fold and largely adding to the cost of steam service, which would of course have a tendency to render the use of electricity economical.

Analyzing the figures obtained from the electric companies, it was estimated that the necessary plant and equipment for operating express trains between the city and the Exposition grounds would cost $1 200 000, divided approximately as follows:

Power plant	$600 000
Wiring and line plant	325 000
Motors in service, extra motors and motor parts	260 000
Repair shop for motors, with necessary machinery and appliances	15 000
	$1 200 000

The annual cost of operation was estimated as follows :

Interest on plant at 5%	$60 000
Operating power plant	85 000
Operation and repairs of motors	101 700
Maintenance of line and wire system	10 000
	$256 700

These estimates were based upon furnishing electric transportation service for the express trains between the city and the Exposition during the Fair period, operating the regular suburban service during the same period by steam, and at the close of the Exposition extending the application of electric power to the entire suburban system. The foregoing estimate would furnish the same maximum capacity per hour as the existing service.

Comparing the estimated annual expense of the electric application with the actual cost of the steam service for the year ending June 30th, 1891, shows the former to be $144 200 in excess of steam for motive power alone. While it is true that trains could be run at more frequent intervals at the same cost, there would, of course, be some additional expense for an increased number of trainmen, etc.; still the electric application would give an increased capacity during a part of the day, which might stimulate and add to the suburban business. In order to justify the extra outlay, however, there would have to be an increase in the suburban business over the year ending June 30th, 1891, of approximately 25 per cent. This would be necessary to offset the extra cost of making the electrical application.

In considering the question of steam *vs.* electricity for the business due to the Exposition, it was found that it would be much more economical to use steam power for this service, and that the equipment necessary for it could afterwards be used for other purposes. It was deemed that it would be advisable, particularly during the busy hours of the morning and evening, to run large units of transportation, as the time consumed in loading and unloading a train would be the same regardless of the length of the train, due to the system which had been decided upon of loading and unloading trains to and from high platforms directly into and out of the sides of the cars, and which afterwards proved so successful; and that it would be safer and more economical to carry a great number of people on heavier trains and run them greater distances apart, rather than have a large number of smaller trains running at short intervals of time. No difficulty was apprehended in running trains of ten or twelve cars each, with a capacity of 1 000 passengers per train, at intervals of three minutes, which would give a capacity of 20 000 passengers per hour. The history of the Exposition more than bore out this theory, as on one night during the hour of heaviest travel, 45 trains were dispatched from the Terminal Station in the Exposition ground, carrying from 1 000 to 1 200 persons each. This was the maximum number of passengers carried in the shortest period of time, and more than exceeded previous expectations.

A factor also in this connection was the fact that it would require from 45 minutes to one hour to make the trip from the Exposition to the heart of the city by the existing cable lines, and at least 30 minutes

by the elevated road; that if electric power was used on the Illinois Central, the tracks would be occupied by such a large number of small units of transportation that it would not be feasible to run them at the speed which would be possible in the handling of large units of transportation by steam at less frequent intervals; and that it would be possible to handle trains between the heart of the city and the Exposition grounds by steam in less than 20 minutes, which would have a tendency to increase the patronage of the Illinois Central line. Experience afterwards proved the correctness of this view, as the average time of the express trains between Van Buren Street and the Midway Plaisance was approximately 12 minutes.

It was therefore decided that while the application of electricity as a motive power might be practicable, it would not be the economical thing to do, and that it was specially undesirable in providing for the large business contemplated during the holding of the Exposition to introduce any elements of uncertainty. The results which could be obtained by the use of steam power were known and definite, both as to economy, efficiency and speed, and it was not considered advisable or economical to adopt electric power for this service.

Deciding the second proposition in the negative rendered it unnecessary to consider at any length the question of appliances except incidentally in determining the question of the economy of electrical application.

It was considered by the author at that time, that, as the use of electric power was rapidly advancing, results would be obtained in the near future which would render its adoption practicable and economical, particularly for terminal and suburban lines.

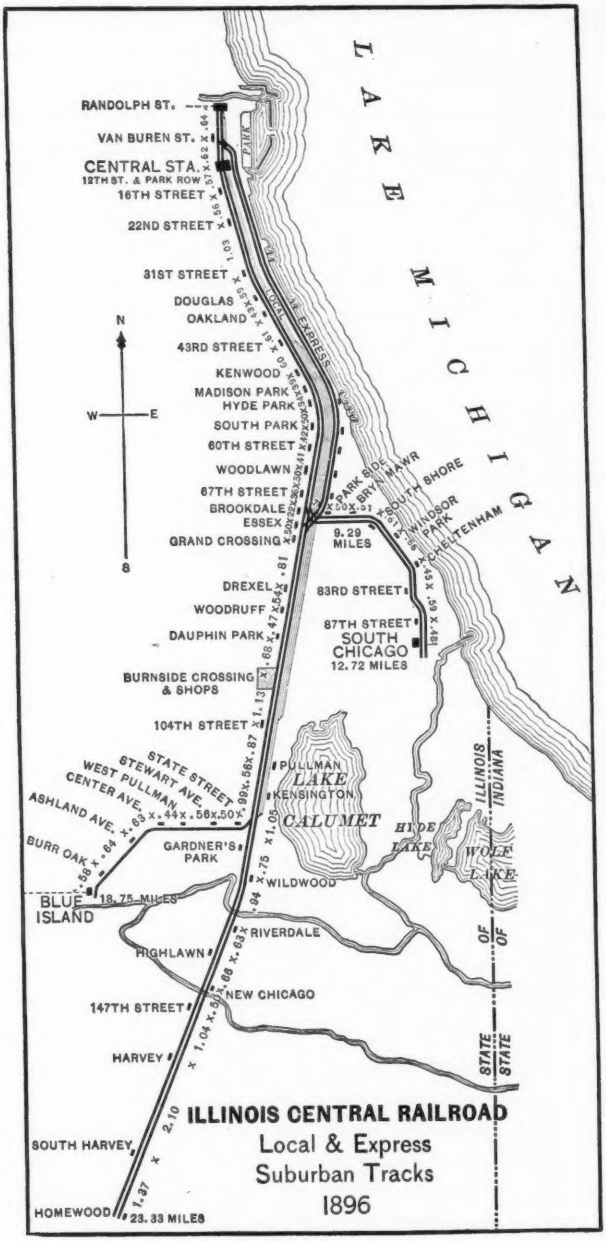
At the time of this investigation, five years ago, while success had been obtained in the adaptation of electricity to street railway systems and small units of transportation over short distances, its application to the larger requirements of terminal and suburban service, which had heretofore been performed by steam power, was yet experimental. The requirements of the Illinois Central service were approximately ten times in excess of the then existing practice, and the adoption of electric power for Illinois Central business, either for World's Fair or the regular suburban traffic, would have been largely experimental and the estimates of the cost of maintenance and operation only approximate.

In discussing verbally the question of appliances, much stress was laid by the representatives of the various electric companies upon the speedy adoption of what is known as the gearless motor; and while they expressed every confidence in the gearless motors which they were manufacturing and had in process of perfecting, the written propositions of some of the companies contemplated the use of single-reduction motors.

The statements of the various electric companies differed largely as to the expense of the application of electric power. For the same capacity their figures varied from $375 000 to $1 200 000. Their opinions of the amount of horse-power needed ranged from 5 000 to 18 000 H.-P. The differences in the estimated cost of operating the power plant per day ran from $232 to $616. In their estimates of the amount of fuel needed per horse-power per hour, the variation is from 2 lbs. to 3½ lbs. of coal. The figures on motors ranged from $7 500 to $10 500; and the cost of operation and repairs of motors per day from $286 to $430. There was a variation in the estimates of the cost of trolley lines and feed wires of from $40 000 to $172 000, and variation in the estimate of repairs to same and other line expenses from nothing to $23 50 per day.

During the five years since this problem was considered, great advances have, of course, been made in the application of electric power, and the cost of appliances has been largely reduced. More certain and reliable data is also doubtless available as to its economy and the cost of maintaining and operating electric power. A number of steam railroad companies are seriously considering the question of replacing their locomotive engines by electric motors for suburban business, and it seems that the general question opens up a wide field for discussion, the results of which should bring into the *Transactions* of the Society a large amount of valuable matter in the line of electric engineering.

Comparing the use of steam and electricity as motive powers, as a general principle it may be stated that electricity is more desirable and economical for handling a large number of small transportation units at frequent intervals over short distances; whereas, steam power is more desirable and economical for handling large units of transportation at high speeds, at infrequent intervals and over long distances. In treating of special applications, it may be further said that the increase in the use of electricity will grow along these general lines.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ILLINOIS CENTRAL RAILROAD
Local & Express
Suburban Tracks
1896

FIG. 2.

Where the substitution of electricity for steam is considered, the question of the disposition of the abandoned steam plants and the amount of money invested therein becomes a factor.

This matter of applying electric power to its suburban service is again under consideration by the Illinois Central Railroad. Fig. 2 is a diagram showing the tracks now devoted exclusively to this service in the city of Chicago. The change from the conditions that existed in 1891 consists in the use of the two west tracks between Randolph Street and Grand Crossing for the local suburban business, trains between these points being so operated as to give a continuous service with trains 20 minutes apart during the hours of light traffic, and from 5 to 10 minutes apart during the busy hours of morning and evening. Ordinarily, these local trains only run as far south as Sixty-third Street, the suburban business from the South Chicago branch, the Blue Island branch, and from the main line at Homewood, Harvey, Kensington, etc., being diverted at Sixty-seventh Street to two tracks along the east side of the right of way, and after making local stops at Sixty-third, Sixtieth, Fifty-seventh and Fifty-third Streets, running from there without stop to Van Buren and Randolph Streets in the city. This forms what is known as the express suburban service. Trains run 20 minutes apart during the day, and 10 minutes apart in the morning and evening, when the traffic is heaviest. The location of these express suburban tracks is such that they are not cut by facing-point switches north of Sixty-seventh Street except at two places; at one of these a Wharton safety switch is used and the other is controlled and protected by the interlocking plant at Forty-third Street. No street crossings exist between these points.

The problem now under consideration is the practicability, desirability and economy of adopting electricity as a motive power for this entire suburban system. Under this general head come minor problems as to the partial adoption of electric power for either the regular or express suburban service or parts thereof, as to the proper location and arrangement of a power house and plant; what system shall be used for the transmission of power; the size of transportation units; whether independent motors of large power should be used to haul long trains of trailers, or whether small transportation units run at more frequent intervals should be adopted, using the motors for carrying passengers. These and many other points are to be considered,

and will be treated by the author in a subsequent paper or in the concluding discussion upon the present paper.

Following is the present amount of equipment assigned to this service: Twenty-one engines, having 16 x 22-in. cylinders, 49½-in.

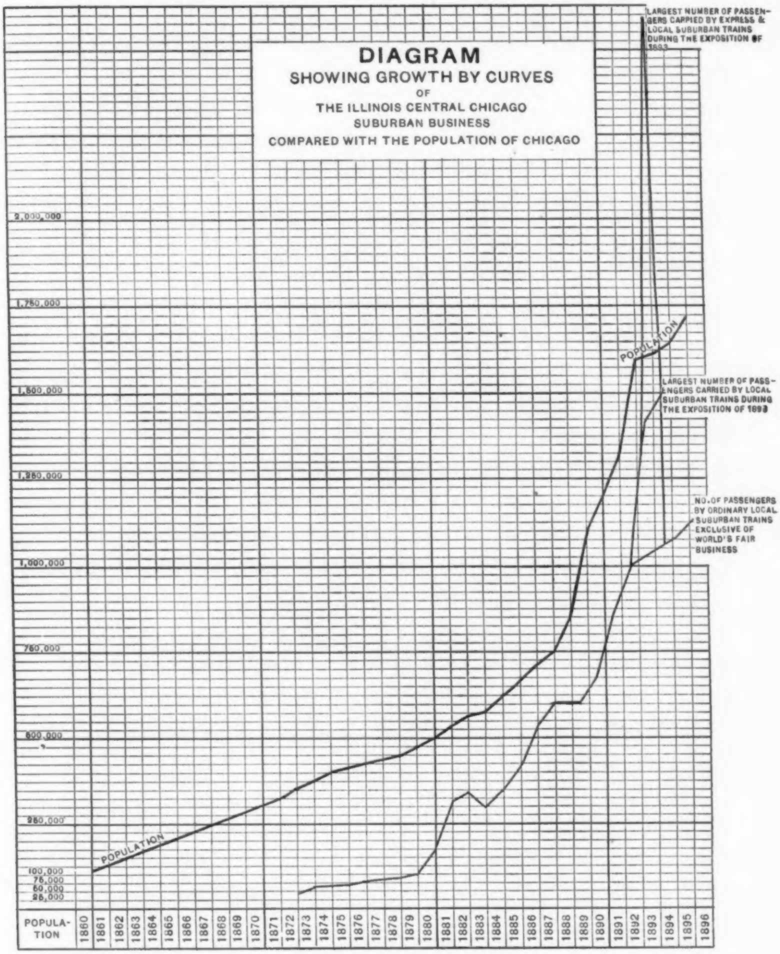

FIG. 3.

drivers, four-wheel; weight, 117 000 lbs. Two engines, having 18 x 22-in. cylinders, 49½-in. drivers, six-wheel; weight, 160 000 lbs. Ten engines, having 17 x 24-in. cylinders, 49½-in. drivers, four-wheel; weight, 166 000 lbs. In all, 33 engines valued at $8 500 each; total value,

$93 500. The suburban coaches in use number 162; they are 45 ft. long and average a seating capacity of 54 persons; value, complete, with steam heat and Pintsch gas, $3 500 each; total value, $567 000. The grand total value of suburban equipment amounts to $660 500.

Fig. 3 is a diagram which shows the increase in the population of the city of Chicago from 1860 to date; also in finer black lines the ratio of increase in Illinois Central suburban business by years. The figures on the left-hand margin show the population, without any reference to the number of passengers carried by the Illinois Central suburban trains. The actual number of passengers carried is not indicated, but simply the ratio of increase year by year. From 1892 to 1894, the lower line shows the suburban business as it would have been unaffected by the Exposition. The lines extending upwards show the proportionate increase in the business due to the Exposition on both the local and express services. The rate of increase in the city's population and the Illinois Central suburban business show a diminished ratio in 1893 and 1894, which was due, so far as the population is concerned, to financial conditions in those years, and as regards the suburban business to the same general influences, together with the competition of the "Alley" elevated line and the growth of local electric lines in outlying districts. It will be noticed that during last year the rate of increase in population and suburban business has again taken an upward turn.

The author has intended in this paper only to introduce the subject of electric transportation to the attention of the American Society of Civil Engineers in the hope that it may draw out valuable discussion and lead to other papers upon this question from experts in this special line of engineering work.

MEMOIRS OF DECEASED MEMBERS.

NOTE.—Memoirs will hereafter be reproduced in the Volumes of *Transactions*. Any information which will amplify the records as here printed, or correct any errors, should be forwarded to the Secretary prior to the final publication.

GENERAL JOSEPH G. TOTTEN, Hon. M. Am. Soc. C. E.*

DIED APRIL 22D, 1864.

General Totten was born in New Haven, Conn., on August 23d, 1788, and graduated at West Point as 2d Lieutenant of Engineers on July 1st, 1805. Resigning in 1806, he served as Secretary to Captain

ERRATA.

Proceedings, DECEMBER, 1896.

PAPERS, page 680:

First line, read "$280 500" instead of "$93 500."
Fourth line, read "$847 500" instead of "$660 500."

tions at Rouse's Point, N. Y., and then became a member of the Board of Engineers charged to prepare plans for defensive works for the sea coast of the United States. Its members were then General Bernard and Lieutenant-Colonel Totten. General Bernard was an able officer of the French Corps du Génie, who was Assistant Engineer in our service from 1816 until 1831, when he returned to France, and subsequently became Minister of War. Although naval officers were sometimes associated with the Board of Engineers, as also the resident engineers of local defences, it was on those two, mainly, that the planning of the defensive works on our seaboard devolved, and a large part of the work was done by General Totten.

The system was prepared and was largely executed in a period when a 42-pounder was one of the heaviest guns on shipboard, and when all naval guns were behind wooden walls. It consisted in defending our harbors by a number of guns which should be more than a match for any probable naval attack, these guns being of power equal to those in the English and other foreign navies, and placed behind masonry walls which were impenetrable to the naval fire of the

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The war of 1812 furnished full opportunity for the display of his ability. He was assigned as Chief Engineer to the army under General Van Rensselaer, and was engaged in the battle of Queenstown in 1812. He was then transferred to the Army of the North as Chief Engineer under General Dearborn, and was engaged in the capture of Fort George. In 1814 he became Chief Engineer of the army on Lake Champlain under Generals Izard and Macomb, and was engaged at the battle of Plattsburg, a place which he had fortified. Previously brevetted Major, he was brevetted Lieutenant-Colonel for gallant conduct at Plattsburg.

From 1817 to 1819 he was the Superintending Engineer of fortifications at Rouse's Point, N. Y., and then became a member of the Board of Engineers charged to prepare plans for defensive works for the sea coast of the United States. Its members were then General Bernard and Lieutenant-Colonel Totten. General Bernard was an able officer of the French Corps du Génie, who was Assistant Engineer in our service from 1816 until 1831, when he returned to France, and subsequently became Minister of War. Although naval officers were sometimes associated with the Board of Engineers, as also the resident engineers of local defences, it was on those two, mainly, that the planning of the defensive works on our seaboard devolved, and a large part of the work was done by General Totten.

The system was prepared and was largely executed in a period when a 42-pounder was one of the heaviest guns on shipboard, and when all naval guns were behind wooden walls. It consisted in defending our harbors by a number of guns which should be more than a match for any probable naval attack, these guns being of power equal to those in the English and other foreign navies, and placed behind masonry walls which were impenetrable to the naval fire of the

* Memoir prepared by Gen. C. B. Comstock, M. Am. Soc. C. E.

day, or behind other effective cover. In similar foreign defences and in the earlier ones of this period built by us, the embrasures were large, and the gunners were seriously exposed to small projectiles. General Totten devised in the latter part of the period a shutter embrasure lined with masses of wrought iron which largely reduced the embrasure opening, and correspondingly diminished the exposure of the gunners. It was an improvement of the highest value, and in 1855–60, when the plans of defence had been carried far toward completion, our system had no superior in the world, and the credit therefor was largely due to General Totten. But at that time, with the gradual introduction of rifled guns of large caliber, and with the possible use of armor on shipboard, the naval vessels of the world, with their wooden walls, became things of the past, and sea-coast defences had to change to meet the new navy.

From 1838 until his death General Totten worked unremittingly at the duty laid upon him of adequately defending the coast of the United States. No question was too large to be considered, no detail too small to be examined by him. His letters were filled with drawings from his own hand, and, in their terseness, clearness and precision, were models for others.

From 1825 to 1838 he was Superintending Engineer of the construction of one of the largest defences in the United States, namely, Fort Adams, R. I. In 1838 he became Colonel and Chief Engineer, U. S. Army, and thereafter his station was in Washington. With this change his duties changed so as to embrace the whole United States. They were so performed as to gain the admiration of all save unscrupulous superiors who could not bend him to their schemes.

In the war with Mexico, General Scott, who had the highest opinion of his ability, made him his Chief Engineer during the siege of Vera Cruz, and he was brevetted Brigadier-General for gallant and meritorious conduct at the siege.

In 1862 he was member of a commission to report on the defensive works at Washington and Alexandria.

In 1863 he was made Brigadier-General; on April 21st, 1864, was brevetted Major-General, and on April 22d, 1864, his useful and noble life ended.

From 1846 until his death he was a Regent of the Smithsonian Institution; a corporator and member of the National Academy of Sciences from March 3d, 1863; and a Member of the Light-House Board from its organization in 1852.

He devoted to his country's service great ability, unswerving honesty and unremitting labor. Gifted by nature with an even, well-balanced mind, he was a courteous gentleman, and, what is deeper, he was a good, kind-hearted man.

General Totten was elected an Honorary Member of the American Society of Civil Engineers March 2d, 1853.

WILLIAM MILNOR ROBERTS, Past-President Am. Soc. C. E.*

DIED JULY 14TH, 1881.

William Milnor Roberts was of Welsh descent. His family were members of the Society of Friends, who came to America with William Penn. They resided in Philadelphia, and a grandfather and an uncle served as mayors of that city. His father's name was Thomas Pascal Roberts. His mother was Mary Louise Baker, and he, their eldest son, was born February 12th, 1810. He was educated at one of the schools of the Society of Friends, taking also two terms of a special course in mathematics under Professor Joseph Roberts. He then became a pupil of the first school established by the Franklin Institute, and there was taught architectural drawing by John Haviland, a well-known architect of that period.

In the spring of 1825, when hardly past his fifteenth birthday, he was made a member of the engineering corps engaged in the construction of the Union Canal of Pennsylvania. From that moment up to the day of his death, in July, 1881, his life was one of continued activity and of devotion to his profession. During those sixty-six years he saw, and in fact was a very important factor in, the wonderful development of public works, which was guided and directed by the civil engineers of America. When he began his engineering service in 1825, there was no railroad in operation in that country. The improvement of means of transportation by water was in active progress. The Erie Canal in New York, begun in 1817, was completed from Buffalo to the Hudson in October, 1825. The State of Pennsylvania had determined by legislative act to adopt and prosecute a canal system. The Chief Engineer who gave a position to William Milnor Roberts was Mr. Canvass White, who had been one of the engineers of the State of New York in the location and construction of the Erie Canal, and who first introduced the use of hydraulic cement in the construction of its masonry, having discovered in 1818 a stone in central New York from which it was made. The chief of the party in which the young man served was Mr. Sylvester Welch, a severe disciplinarian and accomplished engineer. The devotion and energy of the young assistant commended him both to Mr. White and Mr. Welch, and their opinion of him was shown by his rapid promotion to positions of responsibility. Mr. Roberts was really for a number of years both pupil of and assistant to Mr. Welch. In 1826 he was rodman with Mr. White in a survey made across the Allegheny Mountains with special reference to the construction of a macadamized road to connect the water transportation on the eastern and western slopes. In 1827 he was sent by Mr.

* Memoir prepared by John Bogart, M. Am. Soc. C. E.

White as a young assistant upon the survey and construction of the Lehigh Canal, and here he made his first acquaintance with a railroad at the inclined planes at Mauch Chunk. He aided Mr. White in making improvements at those planes, and thus took part in the construction and operation of one of the earliest railroads in the United States. He was one of the passengers on the first trip of the first passenger car actually run on rails in this country.

He continued his service on the Lehigh River and Canal improvement until 1831, when he was appointed Senior Assistant Engineer under Mr. Sylvester Welch, Chief Engineer of the proposed Allegheny Portage Railroad. Surveys and plans for this road had been made in 1829 and 1830 by Mr. Moncure Robinson and by Col. Long, both including eleven planes, although not on the same location. Mr. Roberts suggested to Mr. Welch ten planes, all straight and with inclinations of from 7¼ to 10¼ per cent. He superintended the construction of the five on the eastern slope, and of three on the western slope. In 1832 he rode with Chief Engineer Welch across the country on horseback, and visited the inclined planes on the Morris Canal, and those on the Carbondale and Honesdale Railroad. He spent much time during that year also upon the Western Division of the Pennsylvania Canal, directing repairs made necessary by the great flood of February, 1832. On November 21st, 1833, the Allegheny Portage Railroad was finished, and a train of cars, drawn by horses on the levels, was passed over all the planes. It was opened to the public in 1834. Any persons who chose could put cars upon it, and haul them on the levels with their own horses. Mr. Roberts was given the general charge and management of the running of the road, and continued in this position until January, 1835, when he resigned and was appointed Chief Engineer of the Lancaster and Harrisburg Railroad.

This closed the first ten years of the engineering life of Mr. Roberts. At the age of twenty-five he had become the chief engineer of an important railroad enterprise presenting novel problems of location and construction, and with very little in the whole country to serve as model or guide. There must have been great promise in the young man to lead to his selection for such responsibilities. In fact, he had already developed the characteristics and qualifications which showed so clearly in his subsequent career. The history of that career will be concisely sketched directly.

Mr. Roberts did not have the education of the technical school; in fact, technical schools did not then exist. When he was young, there were no libraries of engineering information. The records of experience and the deductions from such records were in private notebooks, and in correspondence with the very limited number of active engineers. Specialism was not thought of. The varied questions which arose could not be referred—they must be answered at once.

No men could succeed under such circumstances except those specially fitted for the task. Mr. Roberts was a very close and minute observer of physical facts related to engineering problems. He kept voluminous notes, and he had a very retentive memory. He had a special aptitude for design, and an appreciation of what was essential and non-essential in each particular case. He had much mechanical ability, and could draw without instruments a plan which would be surprisingly close to scale. He had in addition untiring energy and extreme devotion to the work of the moment. His diaries and letters and the statements of friends who were associated with him are full of the stories of his remarkable capacity for work. His frequent trips on horseback were for long distances and at great speed, and these never seemed to interfere with his ability for the immediate direction of affairs. In fact his life was of unceasing activity, not only in his younger days, but up to the very last. His physique enabled him to endure great fatigue. He was of moderate height, never corpulent, but of a wiry and muscular frame. In his younger days he was very fond of athletic sports, particularly of skating, in which he was very skillful. He was physically strong and personally brave. On one occasion, at the risk of his own life, he rescued an Indian mother and child who had fallen into Lake Erie from the deck of a steamer on which he was a passenger. In making a reconnaissance of a new region, riding with farmers or guides familiar with the trails, he would astonish them by the accuracy of his estimates of the distances traveled.

He permitted nothing to interfere with professional honesty to his duties. In two particular instances, one quite early in his charge of important work, the other after the war, he tendered his resignation of his position, when an attempt was made to influence politically his engineering appointments.

He was not a student in that sense of the word which is defined as one given to the study of books, but he was a student in the other sense, as one given to the acquisition of knowledge. His writings therefore were generally descriptions of actual observations and expressions of opinion as to the application of experience to new problems. He seldom developed mathematical theories, and he expressed at times doubts as to the reliance to be placed upon a too free use of theoretical formulas, particularly in cases where it could not be certainly known that the existing conditions were the same as those from which the formulas were deduced. The story of his professional life shows that he had a very large opportunity to study the problems of the movement and action of water. He was engaged in the improvement of many important rivers, among them the Monongahela, Ohio, Lehigh, Juniata, Kiskiminetas, Allegheny, Big Beaver, Little Beaver, Des Moines and Mississippi, and he had been during early life in the engineering corps in charge of the

extensive canal works of Pennsylvania. In a letter referring to the discussions upon the vexed questions connected with the improvement of the outlet of the Mississippi he wrote:

"The nice mathematical theories of 'threads of water,' 'waves of translation,' 'radius vector,' etc., are well enough in their proper places. I do not object to them; but if a man has all of these and analogous things at his finger end, and has not practical experience in the actual operation on a large scale of water in rivers and canals, his judgment might easily be at fault when undertaking to plan river works or to criticise river plans. Gravity being the father of the whole thing, of course, he looks carefully after all his children. It is curious how simple things may be made mysterious."

This distrust of too free use of theory did not prevent him from being a welcome associate with many of the most distinguished theoreticians in the practice of engineering science. His wonderful fund of information, his knowledge of engineering facts, his lucid discussions, his unfailing good nature, and his excellently educated common sense, made him always a reliable and successful consulting or chief engineer, and a valuable member of many important commissions.

Mr. Roberts was Chief Engineer of the Lancaster and Harrisburg Railroad during 1835, 1836 and 1837. He located it with a maximum grade of 39.6 ft. per mile, grave doubts existing as to the capacity of a locomotive to haul loads on a steeper grade. At that time grades of 50 ft. per mile were operated in England, as inclines with rope traction. In 1836 he was made Chief Engineer of the Cumberland Valley Railroad, and finished the construction of both lines. During this year he visited Alexandria, Va., where he made a contract for two locomotives; New Castle, Del., one locomotive; Norris Works, Philadelphia, four locomotives; and Lowell, where, however, he could not secure any locomotives because of the extent of previous orders for other roads. In 1837 he built the combination lattice-truss bridge crossing the Susquehanna at Harrisburg, with a double-track railroad on top, and a double carriage-way and footpaths below. In 1838, 1839 and 1840, while still Consulting Engineer for the above-mentioned railroads, he took charge as Chief Engineer in the State service, of the extensions of the State canals of Pennsylvania, the work in progress extending from Erie, southerly, to Pittsburg, and thence still southerly on the Monongahela to the Virginia line, the latter being for the Monongahela Navigation Company. His duties carried him over wide tracts of country which he generally traversed on horseback, keeping three horses in service, and he generally rode from 30 to 40 miles a day, sometimes 50, and once 68 miles. During 1841 and 1842 he was engaged on the enlargement of the Welland Canal in Canada; 1843 and 1844, the Erie Canal of Pennsylvania; 1845 to 1848, Chief Engineer and Trustees' Agent for the Sandy and Beaver Canal in Ohio. During the latter year at the request of the Legislature of Pennsylvania he recommended a line for avoiding the Schuylkill inclined plane near Philadelphia,

which was adopted and built substantially upon the route now used by the Pennsylvania Railroad. In 1849 Mr. Roberts declined the Chief Engineership of the first projected railroad in South America, to accept that of the Bellefontaine and Indiana Railroad where he remained until 1851. From 1852 to 1854 he was Chief Engineer of the Allegheny Valley Railroad, Consulting Engineer for the Atlantic and Mississippi Railroad, contractor for the construction of the Iron Mountain Railroad, and Chairman of a commission of three appointed by the Pennsylvania Legislature upon the reconstruction of the Allegheny Portage Railroad. This commission recommended the abandonment of the inclined planes and the construction of a railroad with maximum grades of 75 ft. per mile, which plan was adopted and the road built by the State. The Pennsylvania Railroad had previously built its line with grades of 95 ft. per mile. The two lines were within sight of each other, and the State railroad was soon after bought by the Pennsylvania.

This was the period of the battle of the railway gauges, and for awhile it seemed that the decision would be in favor of the wider, 6 ft. or more, as against the gauge of 4 ft. 8½ ins. While Chief Engineer of the Allegheny Railroad, which was to connect the Pennsylvania and New York systems, Mr. Roberts strongly advocated the narrow width. The officials of the company at first disagreed with him, and the ties were laid for the wide gauge, but when the rails were placed he succeeded in securing the adoption of what is now the standard gauge.

During 1855, 1856 and 1857 Mr. Roberts was engaged in the construction of the Keokuk, Des Moines and Minnesota Railroad and the Keokuk, Mt. Pleasant and Muscatine Railroad. He was also Consulting Engineer for the Pittsburg and Erie and for the Terre Haute, Vandalia and St. Louis roads. In December, 1857, he went to Brazil; in May, 1858, closed the contract for the construction of the Dom Pedro Segunda Railroad, and as a senior member of a firm built that road. It had thirteen tunnels in 9 miles, one, 7 200 ft. long; there were 3½ miles of tunnel in 9 miles of line. Mr. Roberts was in Brazil until the latter part of 1865, when he took charge of the surveys for the Atlantic and Great Western road, completing them in 1866. He was then appointed on the Commission which recommended the plans for the improvement of the Mississippi River at Keokuk, and in 1866 was appointed United States Civil Engineer in charge of the improvement of navigation of the Ohio River, continuing in this position till 1870. During this time, while on leave, he was in 1868 appointed, at the suggestion of Mr. Eads, Associate Chief Engineer to the St. Louis and Illinois Bridge Company, on the occasion of the visit of Mr. Eads to Europe on account of the serious condition of his health. Mr. Roberts continued in the service of the bridge company two years. He was constantly engaged in conjunction with the other engineers, Messrs.

Flad and Pfeifer and Mr. McComas, the General Superintendent, in the personal direction of the sinking of the caissons of both the east and west piers, a work of novelty, delicacy and danger.

In the fall of 1869 Mr. Roberts became Chief Engineer of the Northern Pacific Railroad and continued in that position until his departure for Brazil in 1879. During this period he made extended surveys and examinations along the various parts of this transcontinental route, including trips over the western mountain passes. In addition to this service he made, in 1873, examinations and a report upon the Marquette and Mackinaw, and upon the Minneapolis and St. Louis Railroads. In 1874 he was made a member of the commission appointed by the President of the United States to examine and report upon the proper method of improving the mouth of the Mississippi. The other members were Gen. H. G. Wright, U. S. A.; Gen. B. S. Alexander, U. S. A.; Gen. C. B. Comstock, U. S. A.; Prof. Henry Mitchell, U. S. Coast Survey; T. E. Sickles, M. Am. Soc. C. E., and H. D. Whitcomb, M. Am. Soc. C. E. This commission visited the mouths of various European rivers. Their report was made January 14th, 1875. In 1874 he also reported upon the water-works of Pittsburg. In 1875 he was a member of a commission to examine and report upon the Water Supply of Philadelphia. He was also a member of the Advisory Commission of Engineers upon the construction of the South Pass jetties at the mouth of the Mississippi River. This board met first on September 2d, 1875. Its members were Gen. J. G. Barnard, U. S. A.; Gen. B. S. Alexander, U. S. A.; Sir Charles A. Hartley, W. Milnor Roberts, T. E. Sickles, M. Am. Soc. C. E.; Prof. Henry Mitchell, U. S. Coast Survey, and H. D. Whitcomb, M. Am. Soc. C. E. This board made its report November 20th, 1875, approving the works in progress.

In 1878 he was in Nova Scotia in connection with the location of the Nova Scotia, Nictaux and Atlantic Railway. In September of that year he was in Washington Territory, and crossed the Cascade Mountains on muleback. In December he concluded a contract for three years with the government of Brazil to act as engineer for that government on any public works, and on January 4th, 1879, left New York for Rio de Janeiro. After his arrival he made examinations of the port of Santos, of the Sao Francisco River, and of the ports of Pernambuco, Fortaleza, Maranhao, Vitoria and Caravellas. He also made a report on the water-works of Rio de Janeiro. On July 2d, 1881, he started to make an examination of the Rio das Velhas. He was compelled to suspend his journey on the 7th at a small settlement called Soledade in the province of Minas Geraes. His indisposition developed into typhoid fever, and he died at that place July 14th. He was buried in a neighboring cemetery, but was afterwards removed and buried in Woodlands Cemetery in Philadelphia, Pa.

Mr. Roberts was highly esteemed in Brazil, and especially by the engineers of that country. After his death the Engineers' Club of

Rio de Janeiro sent to the American Society of Civil Engineers a communication expressing its personal and professional regard and appreciation of the services of Mr. Roberts, and its regret for his sudden death. This communication was accompanied by a bound volume of illustrations of the Dom Pedro Segunda Railroad, which Mr. Roberts began building in 1858, and which was the last railroad over which he traveled.

Mr. Roberts became a member of the American Society of Civil Engineers September 21st, 1870. He was elected Director in November, 1876; was Vice-President November, 1873, to 1876, and November, 1877, to 1878, and was made President of the Society November 6th, 1878. During the Exposition at Philadelphia in 1876 he was Chairman of the Finance Committee of the Centennial Commission of the Society, and devoted much time to the work of that commission. A number of papers and discussions by him have been published in the *Transactions*.

Mr. Roberts married June, 1837, Annie, daughter of Chief Justice John B. Gibson of Pennsylvania. She died in 1857. He married again in November, 1868, Adeline, daughter of Mr. Anthony Beelen, of Pittsburg, who survives him. He had six children by his first wife, and three by the second.

This memoir would be incomplete without a reference to the peculiar charm of the personality of Mr. Roberts. He was eminently social. He was always bright, hopeful, full of anticipation of good results from his earnest work. His character showed clear, straightforward, charming. In troubled seasons, and he had experiences of them, he was ever looking for the sunshine soon to come.

He was a remarkably rapid and voluminous writer, particularly enjoying correspondence with friends. Many of his letters, pages in extent, were written on railway trains, or in the evenings of days which had been so full of work as to tire out all his companions. These letters were witty, cheerful, full of kindly thoughts, and also full of most interesting details of the journey or the professional works which had been seen during the previous days.

He was a most genial companion, in fact he was the cheery life of the assemblages of which he was a part. He had a bright sense of humor, and a constant fund of stories of his varied experiences. He was always very dear to his friends.

His professional life began with the beginnings of American engineering. He took part in the earliest canal constructions, and in those improvements of river navigation which preceded the railway. In the fullness of his experience he aided in the most important development of the treatment of great rivers the world has ever known. He was one of those brave pioneers who built the first railroads of our country; and before the end of his life, he was the chief engineer of a great transcontinental line. With all his achievements and experiences, he was always unassuming, genial, courteous, "a true and kindly gentleman, pure and modest."

JOHN ROBERTS GILLISS, M. Am. Soc. C. E.*

Died July 15th, 1870.

John Roberts Gilliss was of Maryland ancestry, and was born in Washington, D. C., January 4th, 1842. He was the second of three sons of Capt. James M. Gilliss, U. S. N., who, as Lieut. Gilliss, conducted a U. S. naval astronomical expedition to the southern hemisphere in 1849–52, the results of which were published in an elaborate work as an executive document of the 33d Congress, and who, at time of his death in 1865, was in charge of the Naval Observatory at Washington.

The son, John R. Gilliss, had an unusually precocious intellect. His brain was large compared with his body, which was slight and delicate, although his appearance and bearing were in advance of his years. He received his education at a classical school in Georgetown, D. C., graduating at the early age of fifteen, when his teacher told his parents he could take him no farther in mathematics, and presented him with the only gold medal ever given in the school. Being very proficient in this study, he was, while yet a boy, a useful assistant to his father in astronomical computations.

In 1857 he went to Peru with W. W. Evans, M. Am. Soc. C. E., to take the place of Rodman on a railroad then being constructed under the direction of that noted engineer. In a short time, although but sixteen years of age, he was promoted to the charge of a section of 16 miles under construction.

Returning to the United States, he entered the service of the Coast Survey as Aid, and afterwards was engaged during the greater part of the Civil War as a civilian assistant in the Engineer Department of the Army. From 1863 to July, 1865, he was principal Assistant Engineer to Lt.-Col. J. H. Simpson, Chief Engineer of the Department of the Ohio, being engaged all that time on the construction of fortifications in Kentucky. He had charge of the completion of those at Camp Nelson, and designed and built those at Frankfort and Louisville.

At the close of the Civil War, an engineer bureau was organized by the Secretary of the Interior to take charge of the Government interests in the Pacific railroads, and conduct the work of a number of wagon roads in the territories which Congress had placed in care of that department. Mr. Gilliss was made Principal Assistant, July, 1865, under the head of the bureau, Lt.-Col. Simpson, and rendered valuable aid in the preparation of the interesting report of his chief published in 1865. The discussion on the limiting effect of grades on

* Memoir prepared by G. B. Nicholson, M. Am. Soc. C. E.

railroads found in that report was conducted by Mr. Gilliss and was one of the earliest contributions to that subject published.

Desiring further experience in railroad engineering, he took a position in August, 1866, as Assistant to L. M. Clements, Resident Engineer of the Central Pacific Railroad, in the Sierra Nevadas, the work of Mr. Gilliss being principally on the tunnels of that section. A description of the tunnels of the Pacific railroads is found in a paper he read before the Society on January 5th, 1870.*

Having finished his work on the Central Pacific Railroad, he was employed as Engineer in charge of construction on the Union Pacific Railroad, between Wasatch and Castle Rock, on the completion of which he returned to New York, and was engaged on a pneumatic tunnel project in that city, which was never brought to a successful conclusion. He died suddenly of apoplexy of the brain at the home of his mother at West New Brighton, Staten Island, July 15th, 1870, aged 28 years.

Mr. Gilliss was elected a Member of the American Society of Civil Engineers on June 2d, 1869, and a Fellow on March 15th, 1870. He was versatile in his talents; it is not out of place to say, genius. A man of fine executive ability, he had the happy gift of commanding men without his subordinates realizing they were commanded; a charming companion, gentle and unobtrusive in manner, but nevertheless dignified; a constant reader of the best literature, and, while disclaiming that he was a mathematician, often reading works of pure mathematics with as much interest as others would fiction; and notwithstanding his mathematical bent, he had a large artistic talent.

His early death prevented his name from acquiring the renown as an engineer which was so largely promised.

THOMAS JENNINGS SEELY, M. Am. Soc. C. E.†

Died October 2d, 1883.

Thomas Jennings Seely was born at Chester, Orange County, N. Y., August 16th, 1848. He was graduated from the University of Michigan in June, 1869, in both civil and mining engineering, and in a few months began active work in the engineering corps of the La Clede and Fort Scott Railroad Company. In 1871-72 he filled an engineering position on the Decatur and State Line Railroad, and in 1876 was Chief Engineer of the Chicago and Millington Railroad.

* See *Transactions*, Vol. I, p. 153.

† Memoir prepared from information furnished by A. A. Robinson, M. Am. Soc. C. E.

In April, 1878, Mr. Seely was appointed a transitman in the engineering corps of the Atchison, Topeka and Santa Fé Railroad Company, engaged in surveys in New Mexico under Lewis Kingman, M. Am. Soc. C. E. In the fall of 1878 he was made Engineer of Track-Laying on the New Mexico and Southern Pacific Railroad Company, and served in that capacity until 1879, when he was ordered to Kansas to take charge, as Superintendent of Construction, of certain new lateral lines, which the rapid advance in the settlement of the State rendered necessary.

Under his direction and within a trifle over two years from the date of his appointment as Superintendent of Construction, the following lines were built and put in operation: Howard to Eureka, 29.2 miles; Wichita to Caldwell and Arkansas City, 91.9 miles; Burlingame to Manhattan, 56.6 miles; Florence to Ellinwood, by way of McPherson, 98.6 miles; Eldorado to Douglas, 24.3 miles; a total of 300.6 miles.

From the completion of the line from Burlingame to Manhattan until November 1st, 1880, Mr. Seely served as Superintendent in charge. On that date he was relieved of this duty and appointed Superintendent of Water Service of the main line and branches, his jurisdiction extending as far west as Pueblo and Las Vegas. These responsible duties he performed in addition to those of Superintendent of Construction until May 18th, 1881, when the water service was consolidated with the Bridge and Building Department.

In September, 1881, he was made Division Superintendent of the Las Vegas Division, extending from Raton to Wallace, a distance of 206.1 miles, and was also made Assistant Engineer, with direct charge of track, bridges, buildings and water service on his division.

In July, 1882, owing to ill health, Mr. Seely was obliged to resign these positions, and until October of the same year he sought by rest to regain his strength. On October 27th, 1882, he was made General Superintendent of the Sonora Railway, extending from a connection with the New Mexico and Arizona Railroad southward through Sonora to Guaymas, on the Gulf of California. On November 15th of the same year he was advanced to the position of Assistant General Manager of that line. By September, 1883, he was so weakened by consumption that he was forced to resign his position and leave Guaymas. He started for his old home at Oswego, Kendall County, Ill., but on October 2d, 1883, he died in his car just before the train reached Atchison. With him at the time were his wife and two doctors of the railway company's staff.

Mr. Seely was married in September, 1873, to Anzoletta E. Teller, of Oswego, who, with two sons, survived him. He was elected a Member of the American Society of Civil Engineers on February 1st, 1882.

He was never a strong man physically, but he possessed great powers of endurance, was devoted to his profession, and achieved much success in it, as shown by the preceding record.

CHARLES TRUESDELL, M. Am. Soc. C. E.*

DIED APRIL 23D, 1894.

In the death of Charles Truesdell, at Germantown, Pa., on April 23d, 1894, the American Society of Civil Engineers and the profession lost an old and useful member. He was born in Camillus, N. Y., in 1833, and educated in the academies of Onondaga and Madison counties. The son of an engineer, he early manifested a taste for the profession, to which he devoted forty years of his life.

In 1851, at the age of eighteen, he began his professional career under the late John McNair, in locating a railroad from Fort Niagara to Chippewa, on the Canadian frontier, and in the construction of the railroad from Lewiston to Niagara Falls. He was next associated with Hon. George Geddis in the service of the State of New York in surveys for the removal of the bar in Seneca River at Jack's Reefs. In 1853, under the late Hon. Van R. Richmond, he entered the service of the State of New York in enlarging the Erie Canal, subsequently having charge of some of the most important works on the canals, among them the new channel for Canandaigua River outlet, extensive dredging of Seneca River, the high embankments across the Montezuma marshes, and the Seneca River aqueduct. He continued in the service of the State many years in various capacities, and was appointed by the Governor to superintend the development of the salt wells at Montezuma.

He was Chief Engineer of the Cayuga Marsh Improvement Company, Chief Engineer in charge of surveys and location for a railroad from Chittenango to Cazenovia, N. Y., and was inspector in charge of the extension of harbor works at Cleveland, O., under the late General T. J. Cram and Major Walter McFarland, of the Corps of Engineers, U. S. Army. This position he resigned in 1868 to accept the appointment of Division Engineer in charge of the Uintah Division of the Union Pacific Railroad in Utah, continuing in that position until the road was completed in the fall of 1869. As Resident Engineer under Chief Engineer D. H. Wood, he had charge of the location and construction of the Montclair Railroad, now known as the Greenwood Lake Railroad, from Jersey City to Greenwood Lake, covering a period of about four years. At the expiration of this time he returned to the service of the State of New York, and was in charge of the construction of the State dam at the outlet of the Cazenovia Lake, of the completion of the Oneida Lake Canal, and of repairs to dams on Oswego River and Chenango Canal reservoirs and feeders. He was Chief Engineer for the Syracuse Water Company, and subsequently Resident Engineer in charge

* Memoir prepared by Colonel George Truesdell, U. S. Army, and Major C. W. Raymond, M. Am. Soc. C. E.

of location and construction of the Delaware Division of the New York, Susquehanna and Western Railroad in New Jersey and Pennsylvania.

In 1891 Mr. Truesdell was appointed Assistant Engineer upon the extensive improvement of the harbor of Philadelphia under Major C. W. Raymond, M. Am. Soc. C. E. In this very responsible position he continued until his death, and he won the confidence, affection and respect of all his associates. He had a keen sense of responsibility and was earnestly devoted to duty, even while suffering from his last illness. Industrious and persevering to a remarkable degree, he was never contented until he discovered what he thought was the best solution of any problem, and his judgment was seldom at fault. He had a high sense of honor, was unselfish, kind and affectionate in all his family relations, and faithful in every relation of life.

In 1869 he married Mary Bradford, youngest daughter of Colonel John M. Fessenden, of Boston, Mass. Two children survive him, John Fessenden and Harriet T., wife of Carl Hering, an electrical engineer. He was elected a Member of the American Society of Civil Engineers September 15th, 1869.

ISAAC MUNROE ST. JOHN, M. Am. Soc. C. E.*

Died April 7th, 1880.

General Isaac Munroe St. John, eldest child of Isaac R. and Abby R. (Munroe) St. John, was born November 19th, 1827, at Augusta, Ga., where his father was then engaged in business. He graduated from Yale College with the degree of B. A. in the class of 1845, and received his degree of M. A. from that college in 1848.

On graduating he began the study of law in New York, but removed to Baltimore in 1847, where he was employed as Assistant Editor of the *Patriot.* He subsequently chose civil engineering as a profession, and was connected with the engineering corps of the Baltimore and Ohio Railroad until 1855. In that year he removed to Georgia, and was in charge of divisions of the Blue Ridge Railroad for five years.

In February, 1861, he entered the Confederate service as a private in the Fort Hill Guards of the South Carolina State troops. Two months later he was transferred to engineer duty, and rose rapidly to the position of Chief Engineer of the Army of the Peninsula. In May, 1862, he was made Major and Chief of the Mining and Nitre Bureau Corps. He was promoted through the various grades to the rank of Brigadier-General, and in 1865 to the position of Commissary General of the Confederacy.

* Memoir prepared by Edwin A. Hill, M. Am. Soc. C. E.

After the war he resumed his profession, and from 1866 to 1869 was Chief Engineer of the Louisville, Cincinnati and Lexington Railroad. In 1870 and 1871 he was City Engineer of Louisville, Ky. From 1871 until his death he was Consulting Engineer of the Chesapeake and Ohio Railroad.

He was elected a member of the American Society of Civil Engineers on July 14th, 1871.

During the war he married a daughter of Colonel J. L. Carrington, of Richmond, Va. He died suddenly at his residence at White Sulphur Springs, W. Va., April 7th, 1880, aged fifty-two years.

JOHN CHAMBERS THOMPSON, M. Am. Soc. C. E.*

Died January 17th, 1880.

John Chambers Thompson was the son of Jared and Jane Anthony, and was born in Philadelphia, Pa., February 5th, 1844. After the death of both parents, he was adopted by the Rev. Dr. Thompson, at that time preaching in Philadelphia, and his name was changed from Anthony to Thompson.

He was graduated from the Rensselaer Polytechnic Institute in the class of 1865, and was soon engaged as Assistant Superintendent of Construction of the Bessemer Steel Works of Messrs. Winslow, Griswold & Holley, of Troy, N. Y. He retained this position for two years, and then became Superintendent of the plant for about a year.

In 1868 he was appointed Assistant Engineer on the Croton Water-Works of New York City, and in 1870 held a similar position in the Department of Public Works of that city. In 1872 he again became Superintendent of the Bessemer Steel Works at Troy, and remained there for two years, when he went to the Crown Point Iron Company at Crown Point, N. Y., as Superintendent of its railroad department.

From 1877 to 1879 he was Assistant Engineer of the Croton Water-Works of New York City, and was subsequently connected for a short time with steel works at Cleveland, O.

His health then began to fail, and he went to Minnesota to recuperate. Consumption had attacked him, however, and he died of this disease on January 17th, 1880.

Mr. Thompson was a man very much beloved by those who knew him, of genial disposition and a thorough student. In the various positions held by him, he gave satisfaction to his employers, and his early death was a loss to the profession, in which, had his life been spared, he would no doubt have taken a prominent position.

He was elected a Member of the American Society of Civil Engineers on May 18th, 1870.

* Memoir prepared from a "Biographical Record of the Officers and Graduates of the Rensselaer Polytechnic Institute," by Professor H. B. Nason, and from information furnished by William H. Wiley, M. Am. Soc. C. E.

HENRY WARD BEECHER PHINNEY, M. Am. Soc. C. E.*

Died November 22d, 1888.

Henry Ward Beecher Phinney was born in Jay, Me., January 28th, 1854.

In May, 1875, he entered the office of Shedd & Sawyer, Civil Engineers, in Boston, Mass., as student and apprentice, and was employed on the construction of water-works at Newton, Mass., and in charge of pile-driving on the main sewer at Brookline, Mass.

From 1878 to 1882 he was employed under Howard A. Carson, M. Am. Soc. C. E., on the construction of the improved sewer system of Boston, Mass., as Assistant Engineer and Foreman, having charge of many important structures. In March, 1882, he took charge of the construction of the receiving well for the Indianapolis, Ind., Water Company, 12 ft. in diameter and 30 ft. deep, through saturated gravel on the bank of White River, under the direction of J. J. R. Croes, M. Am. Soc. C. E. On the completion of this work he was employed by Mr. Croes as Resident Engineer of the construction of the water-works at Princeton, N. J., and afterwards, from 1883 to 1886, as Resident Engineer of the Suburban Rapid Transit Company, having charge of the surveys and the construction of the Harlem River Bridge, and the brick and iron viaducts in Morrisania, New York City.

Pulmonary disease compelled him to resign this position on December 1st, 1886, and he went to Pasadena, Cal., where he died on November 22d, 1888.

Mr. Phinney was accurate and painstaking in all his work, and was an excellent organizer and superintendent of labor, a good draftsman and computer, and a rigid and at the same time judicious supervisor of the construction of works.

He became a Member of the Boston Society of Civil Engineers in October, 1879, and of the American Society of Civil Engineers on January 7th, 1885.

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* Memoir prepared by J. J. R. Croes, M. Am. Soc. C. E.

CHARLES WOOD, Assoc. M. Am. Soc. C. E.*

DIED NOVEMBER 28TH, 1895.

Charles Wood was born in Edinburgh, Scotland, January 8th, 1862. He was educated in the Academy of that city. It was his early ambition to obtain a position in the Royal Engineers, but circumstances changed his plans. To perfect his knowledge of the French language, he studied a year in France. This was about 1878. In 1881 he came to America. In April of that year he found employment in the mechanical drawing-room of the Edge Moor Iron Works, where he was engaged until June, 1882. Doubtless his experience there brought him to realize the importance of a more thorough technical education as a preparation for his chosen profession, and, in the autumn of 1882, he entered the Massachusetts Institute of Technology, from which he graduated in 1886, with high rank in his class. The subject of his thesis was a design for a cantilever bridge over the St. Lawrence River at Lachine, P. Q. To familiarize himself with the requirements of the problem, he spent a vacation at Lachine.

There is abundant testimony that while at the Institute he was an earnest and faithful student, a leader among his fellows, and that he was held in the highest esteem by both faculty and students. During the vacation in 1884, he was employed in the bridge erection force of the Chicago, Milwaukee and St. Paul Railroad.

On the completion of his course at the Institute, he was at once offered a position in the drafting-room of the Boston Bridge Works, where he remained until October of the same year, at which time he accepted a position in the drafting-room of the Keystone Bridge Company. From January to May, 1887, he was engaged on special drawings for the terminals of the Minnesota and Northwestern Railroad at St. Paul, Minn. In May, 1887, he accepted a position with the Pittsburg Testing Laboratory, to inspect shop work at Athens, Pa., for the Poughkeepsie Bridge, inspecting also bridge-work at the Union Bridge Company's shops at Rochester, N. Y., and bridge material at the Elmira Rolling Mill. On January 15th, 1888, he entered upon an engagement as Assistant Engineer on the Cincinnati, Hamilton and Dayton Railroad, Joseph Ramsey, Jr., M. Soc. C. E., being Chief Engineer of the road. Upon Mr. Ramsey's retirement, to accept the position of Assistant to the President of the Cleveland, Cincinnati, Chicago and St. Louis Railroad, Mr. Wood became Acting Chief Engineer, and, in August, 1891, was appointed Chief Engineer of the Cincinnati,

* Memoir prepared by S. Whinery, M. Am. Soc. C. E.

Hamilton and Dayton Railroad system, a position he held with ability and honor until his death.

During this engagement extensive improvements were made on the road, embracing bridge renewals, the erection of an iron freight house at Cincinnati, and the construction of a large modern grain elevator at Toledo, O. The maintenance of way department was also under Mr. Wood's charge. During this time he resided in the village of Wyoming, a suburb of Cincinnati, and was one of three commissioners, Mr. Ramsey being another, appointed to design and construct a system of water supply for the village. After Mr. Ramsey removed to St. Louis, the mechanical and technical work of the commission fell largely to Mr. Wood, and to him was due in no small measure the practical success of the enterprise. He was re-elected to the position, which he held at the time of his death.

In the early part of the summer of 1895 Mr. Wood was taken sick with what his physician thought to be some disorder of the digestive system, and he was forced to discontinue all work for a time. Later in the season he was able to be at his office a few hours nearly every day, but there was no permanent improvement in his condition. As autumn came on he was confined to his home. Later his physician surmised that his malady was of a more serious nature than had been suspected, and a surgical operation, which was deemed advisable, disclosed that he was a victim of cancer of the stomach. He did not rally from the operation, and died on November 28th, 1895.

Mr. Wood became an Associate Member of the American Society of Civil Engineers July 4th, 1894. He was also a member of the Engineers' Club of Cincinnati, to which he contributed valuable papers. He took great interest in the American Society of Civil Engineers, and before his death collected notes for a paper for the Society on "The Construction of Grain Elevators." It is to be greatly regretted that he did not live to complete this paper, as it would have been of great practical value to the profession.

Mr. Wood was especially fond of structural work, and, while able and efficient in other departments, he developed unusual aptitude and talent in designing bridges and other structures. He was an energetic and tireless worker, who loved his profession next to his family and home. His friends have good reason to believe that had he not been cut off in his early manhood, he would have attained a front rank in his profession. In his business intercourse he was affable, courteous, considerate and just, and, at the same time, outspoken and decisive.

Letters to the writer since Mr. Wood's death, from instructors and fellow students at college, and from business and professional associates since his graduation, all bear strong testimony to his ability and sterling character. Mr. M. D. Woodford, President of the Cin-

cinnati, Hamilton and Dayton Railway Company, in a letter, dated January 13th, 1896, pays this high tribute to him as a man and a civil engineer:

"In the death of Mr. Wood, which was greatly deplored, the Cincinnati, Hamilton and Dayton Railway has lost a valuable official, whose eminent personal and professional qualities merited my most sincere appreciation.

"Mr. Wood commenced his service with the Cincinnati, Hamilton and Dayton Railway in January, 1888, as Assistant Engineer, which position he filled so creditably that in January, 1890, he was promoted to the position of Acting Chief Engineer, which afforded him an opportunity to demonstrate his ability, which was soon recognized by his appointment in August, 1891, to the office of Chief Engineer.

"Being well equipped by education and experience, he performed the duties of that office with marked success. Proficient in all branches of his profession, his forte was bridge engineering. He was also an expert in structural work. During the eight years of his connection with the Cincinnati, Hamilton and Dayton Railway Company much exceptionally important work was done under his supervision, which bears testimony to his excellent judgment and qualifications as an engineer, notably the planning and construction of our extensive Ivorydale yards, the erection of new freight houses at Cincinnati, the construction of a large grain elevator at Toledo, O., and the building of bridges over Silver Creek, Big Williams Creek and the Miami River.

"In his personal life he was esteemed and beloved for his splendid qualities of mind and heart, for his conscientious sense of duty and the high principles by which he was ever guided. Affable and courteous in his manners, his relations with all with whom he was brought in contact were at all times cordial and pleasant. Owing to his extreme modesty and his aversion to putting himself forward, only those who knew him intimately or were closely associated with him thoroughly appreciated his true value. Cut off by the Dread Reaper so early in his career, it is sad to think that a life of great usefulness and promise is ended just in its prime."

Mr. Wood's professional and business associates uniformly speak in the highest terms of praise of his personal and professional honor, his integrity, reliability and conscientious character. In his personal and social relations he was respected by all, and esteemed and beloved by his many friends for his sterling qualities of mind and heart.

Mr. Wood was married in May, 1890, to Miss Ruth Cowing, of Wyoming, O., who, with two children, survive to mourn the untimely loss of a most devoted husband and father.

FRANK BERESFORD, Jun. Am. Soc. C. E.*

Died December 12th, 1887.

Frank Beresford was born at Cincinnati, O., on April 20th, 1861, and resided in that city for most of his life. He graduated from the civil engineering department of the University of Cincinnati in 1884, and immediately entered the engineer's office of the Cincinnati, New Orleans and Texas Pacific Railroad Company. His stay there lasted but a few months, however, for he entered the service of the Cincinnati, Hamilton and Dayton Railroad Company in September of that year, where he remained until his death.

His progress in his profession was quite rapid, for in the course of a year he rose from the position of Draftsman to that of Principal Assistant Engineer, with charge of the drafting, field work, bridge designing and inspecting. He was engaged in the discharge of these duties at the time of his death, which occurred on December 12th, 1887. His attainments as an engineer were exceptional for a man of his years, and his high character won him many friends. An intimate acquaintance, Joseph Ramsey, Jr., M. Am. Soc. C. E., writes as follows concerning him :

"In my opinion, his death was a great loss to the engineering profession, as I considered him one of the brightest and most promising engineers I ever had any connection with. He was a thorough-going, efficient and capable man, and had one of the most upright, honorable characters of any of my acquaintances."

Mr. Beresford was elected a Junior of the American Society of Civil Engineers on September 7th, 1887.

WILLIAM C. KINGSLEY, F. Am. Soc. C. E.†

Died February 21st, 1885.

William C. Kingsley was born in Fort Covington, Franklin County, N. Y., July 31st, 1833. His father was a farmer, and Mr. Kingsley's boyhood was passed uneventfully upon the farm, where he rendered faithful, painstaking assistance during the summer months. In the winter he attended school, learning readily and showing marked aptitude for mathematical work and great fondness for history.

Before he reached manhood he had acquired such an education as the village school could furnish, and, as he was an omnivorous reader, he had stored away much valuable knowledge gained from works borrowed from neighbors and otherwise obtained, in addition to that

* Memoir prepared from information on file at the House of the Society.

† Memoir received through C. C. Martin, M. Am. Soc. C. E.

acquired at school. Young Kingsley realized very early in life that, attractive as the life of a farmer might be to some, it was not the life for him, and he resolved to leave the parental roof-tree and strike out for himself, a resolution which, once having made, he quickly put into execution.

He started out with the benedictions and blessings of his parents, who had reluctantly consented to his going. He had no definite plan of action, but a fixed purpose to do something which should at least satisfy the yearnings of his soul and enable him to exert to the utmost the powers which he knew were his. He found employment immediately with a railway company which was engaged in constructing a railroad in Westmoreland County, Pa. His duties were clerical, but he brought so much intelligence, fidelity and zeal to bear on their performance as to stamp him at once as a man of no mean ability; but, just as his employers were about to show their recognition of his excellent service, typhoid fever prostrated him, and he lay precariously ill for many weeks. Good habits and previous good health proved their efficient help in assisting him through the terrible illness, but his recovery was slow and the importance of outdoor exercise apparent. Unwilling to remain idle one hour longer than was absolutely necessary, young Kingsley applied for and secured a position as teacher in a school in New Alexandria, without, however, any idea of choosing teaching as a profession. He was singularly successful, acquiring vast influence over his pupils, who recognized in him a master who was a friend as well. His labors in the schoolroom were marked by the same conscientious devotion and industrious, painstaking efforts as had characterized everything he had undertaken from his earliest childhood. During his incumbency as teacher an emeute occurred among the scholars, led by some of the older, more obstreperous pupils. The skill, judgment and courage with which he met the matter attracted the attention of Col. Snodgrass, who had been accidentally a witness to the fracas. Recognizing immediately the inherent qualities which had enabled the young teacher to so successfully and triumphantly terminate a rather serious difficulty, Col. Snodgrass determined to befriend the young man, and to that end tendered him a position as bookkeeper. Mr. Kingsley accepted the offer, and at once entered upon his duties.

Col. Snodgrass was at this time engaged in building a large canal in Wyoming, Pa. The region thereabout is extremely wild and mountainous, conditions which rendered the work one of great difficulty, which was materially increased by the continual disturbances occurring among the employees, who were, in many cases, as wild as the country about them. Strikes were frequent, and race and clan fights numerous. When young Kingsley arrived, disorganization was complete. He at once, in the absence of his employer, took charge, and in a short time succeeded in restoring order and bringing about a more amicable feeling among the men ; gave a new impetus to the

work, which had been dragging along for several years, and in a year and a half brought it to a profitable and successful completion.

He remained for eighteen months afterwards with Col. Snodgrass, executing meanwhile for him a contract for the construction of the great tunnel between Altoona and Johnstown. Upon the completion of this work Mr. Kingsley felt himself master of the contracting business, and determined to go west on a tour of observation. He sojourned in Illinois and Wisconsin for some time, and built railroads and other works, always with great success.

Returning to the East, he settled in Brooklyn, then little more than an extensive village. He was immediately recognized as a man of unusual ability and promise, though but twenty-four years of age.

The water-works of Brooklyn were then in process of construction, and a part of the work was sublet to William Kingsley, and the manner in which his part was performed placed him in the front rank among contractors and engineers. About this time he entered into partnership with Col. Abner C. Keeney, a man of great energy and business capacity, and one who proved himself invaluable as a colaborer and friend. As such he remained until his death. The firm thus formed was awarded the contract for sewering the city of Brooklyn, and more than 65 miles of subways were built under the streets. At the same time, Messrs. Kingsley and Keeney built the Wallabout improvements, and railway lines in Pennsylvania and New York. The Hudson Avenue and the Third Avenue sewers, the stone walls around Central Park in New York, and Washington Park in Brooklyn, were also built by this firm. The greatest of their undertakings as partners was the storage reservoir at Hempstead, N. Y. Many difficulties in excavating and other matters had to be met and overcome in order to create the basin, which was built to hold a million gallons of water in reserve. When completed it was flawless, and remains so to-day.

To William C. Kingsley, more than to any other man, are Brooklyn and New York indebted for the great bridge which spans the East River. He conceived the project, and, after consultation with an eminent engineer, who framed the tremendous scheme, set himself to work to overcome monster objections and obstacles of every kind, to effect legislation in favor of the great enterprise. Not once did he falter, though assailed and vilified and hampered in all possible ways. For two years he lived with this thought uppermost in his mind, always actively urging it, and finally securing the necessary legislation authorizing the commencement of the work. A private corporation was first formed, with the two cities as contributors, Brooklyn contributing two-thirds, and New York one-third, to the capital stock, and the incorporators subscribing half a million dollars themselves as an earnest of their faith in the project. Of this sum Messrs. Kingsley and Keeney subscribed over three-fifths. It is not the purpose of this memoir to enter exhaustively into the various stages of the

construction of the bridge. Suffice it to record that colossal obstacles and hindrances—the result in some instances of ignorance, in others of jealousy—were constantly being placed in the way as barriers to its successful termination. A less courageous man than William C. Kingsley would have failed in the work, but neither the virulence of his enemies, nor the ignorance of the many who sought to prove its impracticability, served to turn him a hair's breadth from the path he had laid out. The bridge must be built, and he must not and would not rest until it was an actuality. From a private enterprise, the building of the bridge became a public undertaking, largely through the influence of Mr. Kingsley, who foresaw its necessity to insure the success of the undertaking.

He became a member of the Board of Trustees, and of every successive board he continued a member. Through him the services of John A. Roebling were secured as Engineer of the bridge. From that moment the engineering success of the structure was assured.

It is a well-established fact that to the genius of Roebling as an engineer, and to that of Kingsley as a builder, are directly traceable the successful construction of the bridge.

John A. Roebling met his death in the performance of his duty, and his son, Washington A. Roebling, was appointed as a worthy successor of his father, and, though prostrated for months by an illness contracted in the work, directed the construction to the end.

On May 24th, 1883, the bridge was formally presented to the two cities. In that hour, all the difficulties which had beset his path, were forgotten by William C. Kingsley in the supreme vindication which was his, in the enduring monument which was to ever after stand attesting the triumph of his genius and fortitude.

Having completed his work as builder, Mr. Kingsley tendered his resignation as a Trustee, which was accepted with the deepest sorrow by his coadjutors, who honored and loved him.

Mr. Kingsley was a man of imposing stature and figure, and, wherever he appeared, at once commanded respectful attention. Modest to a degree, he never sought nor toiled for fame.

In politics he was a Democrat, and many a campaign victory could be directly traced to his magnificent skill in organizing party forces. Mr. Kingsley, though importuned again and again to fill very responsible and honorable offices, never did so, but was content to wield his influence in a way best calculated to advance the interests of the country and community.

He was elected a Fellow of the American Society of Civil Engineers on June 6th, 1870.

His death occurred on February 21st, 1885, after a week's illness, with pneumonia and peritonitis. The entire city mourned the loss of a citizen who had served it with all the forces he could command, in a path of unswerving integrity.

GEORGE WASHINGTON CASS, Jr., F. Am. Soc. C. E.*

DIED MAY 21ST, 1888.

George Washington Cass, Jr., was born on his father's lands, near Dresden, Muskingum County, Ohio, on March 12th, 1810. He was the oldest child of George Washington Cass and Sophia Lord, and grandson of Jonathan Cass, a Captain of volunteers in the Continental Army, and afterwards a Major in the U. S. Army. Jonathan Cass lived in Exeter, N. H., and moved with his wife, Mary Gilman, and family in 1800 to Ohio, where he settled finally on the Muskingum River near Dresden. Owing to the schools in that new region being of the most elementary character, George W. Cass, Jr., was sent to Detroit, Mich., in 1824 for the purpose of being educated at the Detroit Academy, then under the charge of Rev. Ashbel Wells, and while there he lived with his uncle, Lewis Cass, at that time Governor of Michigan Territory. Four years later he obtained an appointment from his native state as a cadet at the U. S. Military Academy at West Point, and graduated from there in June, 1832, at the head of his class in the principal studies, and among the first five in general academic studies.

Instead of receiving the usual two months' leave of absence on graduating, he was at once ordered to report to General Scott, then in New York organizing an army to proceed against the Indians, who were collected in large numbers in the Northwest under Black Hawk. Although having only the rank of cadet, he was placed in command of a company of infantry just recruited into service, and assigned to that portion of the army under General Twiggs. On the way to the frontier the command of General Twiggs was so much reduced in numbers by the Asiatic cholera that a number of companies were broken up for the purpose of filling others to a proper complement, and thus, the number of officers being in excess of the demand for service, Capt. Cass was transferred to the Department of Topographical Engineers. He served six months in this department, and was then transferred to the Department of Military Engineers, in which he remained until October, 1836, when, resigning his position, he received from President Jackson an appointment of Civil Engineer on the National Road, in which capacity he continued until the completion of that road in the states of Virginia, Maryland and Pennsylvania. During this service Capt. Cass erected over Durlap's Creek, a tributary to the Monongahela River, the first cast-iron bridge ever built in the United States.

*Memoir prepared by Cass K. Shelby, Esq.

He was an early and persistent advocate of the improvements of the Monongahela River by locks and dams, and contributed to the procuring of the charter and organization of a company. As its engineer, he made the survey and located and superintended the construction of locks Nos. 3 and 4. After the suspension of the work by the inability of the State of Pennsylvania to pay its appropriation, and the sale of the State stock to private parties, he was a member of the Board of Managers, and was actively instrumental in organizing a company from the new shareholders and the framing of a contract which insured the completion of the work in 1844.

On the completion of the Monongahela improvements to Brownsville, Pa., he organized the first steamboat line on that river, and also the first fast transportation lines across the mountains by relays of teams similar to stage lines, thus building up a large carrying trade between the East and the West *via* the Monongahela River and Pittsburg.

In 1849 he established the Adams Express across the mountains from Baltimore, effected the consolidation of all the Adams Express lines between Boston and St. Louis, and south to Richmond in 1854, and in the year following was elected President of the consolidated company, with offices in Pittsburg, Pa.

In January, 1856, he was elected President of the Ohio and Pennsylvania Railroad Company, then possessing a road completed to Crestline. This line was finally extended to Pittsburg and Chicago, and became the Pittsburg, Fort Wayne and Chicago Railway. Mr. Cass remained at the head of this company for twenty-five years. In 1859 he was appointed a member of the Board of Visitors to the U. S. Military Academy. He was also president of the Continental Improvement Company of Pittsburg which built the Grand Rapids and Indiana Railroad.

Mr. Cass was one of the Commissioners named by Congress to organize the Union Pacific Railroad Company, and was a member of the first Board of Directors of that company. He declined the office of treasurer and president. He also became a member of the Smith syndicate which took possession of the franchise and debts of the Northern Pacific Railroad Company in 1866, and became greatly interested in the development of the Northwest. When the Northern Pacific Railroad was constructed and put into operation, he became its president on October 1st, 1872, and transferred his residence from Pittsburg to New York City. He was at this time also President of the Southern Railway Security Company which controlled the properties of the East Tennessee, Virginia and Georgia Railroad and other southern lines. While connected with the Northern Pacific system Mr. Cass bought a tract of land seventeen miles west of Fargo, No. Dak., having in view the cultivation of wheat in that region. At the

same time Mr. Charles P. Cheney, of Boston, bought lands adjoining, and jointly they engaged the services of Oliver Dalrymple to superintend the united estate, which became known as the famous Cass-Cheney farm. Mr. Cass resigned his office of president of the Northern Pacific Railroad in 1875 to take the receivership of that company, and after the reorganization in August following he went to Europe for a rest. With the exception of a visit home the next year, he remained abroad until the spring of 1881.

Mr. Cass did not again engage in active business after severing his connection with the Northern Pacific. He continued to live in New York City, however, where he died March 21st, 1888.

George W. Cass married first, January 5th, 1835, Louisa Smith, second daughter of George and Mary (Kennedy) Dawson, of Brownsville, Pa., and had by her one child, a daughter. His wife died at Dresden, O., seven years after, and he married secondly, September 14th, 1843, Ellen, the third daughter of George Dawson, of Brownsville, and had by her five sons and six daughters.

He was elected a Fellow of the American Society of Civil Engineers on March 30th, 1871.

SIDNEY DILLON, F. Am. Soc. C. E.*

Died June 9th, 1892.

Sidney Dillon, the well-known financier and contractor for railroads having a total length variously estimated at 2 500 to 3 000 miles and costing from $75 000 000 to $100 000 000, was a farmer's boy in early life. He was born on May 7th, 1812, in Northampton, Montgomery County, N. Y., where the family had resided for several generations. His grandfather was a Revolutionary soldier, and was present at the surrender of Burgoyne. Young Dillon was brought up like most boys in similar conditions at the time, receiving as good an education as the local schools afforded.

His railroad career began as an errand boy on the Mohawk and Hudson Railroad from Albany to Schenectady, and when this road was finished, he was employed in a similar capacity on the Rensselaer and Saratoga Railroad. Later, he became an overseer for Crane & Clark, who had a contract on the Boston and Providence Railroad near Sharon, and remained with them for two years, until the contract was completed. Then he was made a foreman for the same firm on its contracts on the Stonington road in Connecticut and on heavy rock work near Charlton, Mass., on the Western Railway, now part of the Boston

*Memoir prepared in the office of the American Society of Civil Engineers.

and Albany line. In the latter position he had the good fortune to become intimately acquainted with Capt. W. H. Swift, at that time the engineer in charge of work. Capt. Swift took a strong interest in the young man, and when it came time to put in bids for new work urged him to make tenders on his own account. Mr. Dillon had little money at the time, but he thought he saw his way clear to undertaking a small section near Hinsdale. His bid was accepted and the work was completed satisfactorily in 1840.

This was the beginning of a contracting career of unusual extent and success. Mr. Dillon is described by those who were acquainted with him about this time as an unusually fine leader of men. Over 6 ft. tall, heavily built yet active, and speaking in a direct, incisive manner, he conveyed the impression of a man who knew what to do and how to do it, and was fully able to command others in carrying out his plans. His second contract was on the Troy and Schenectady Railway, where he took some heavy work in clay about 2 miles from Troy, which was carried out by means of a steam shovel. Then he became a member of the firm of Boody, Ross & Dillon, which built 6 miles of the Cheshire Railroad in Vermont and the Hartford and Springfield Railway, 26 miles long, part of the payment of the latter being made in stock. At this time he also had an individual contract to construct 6 miles of difficult line on the Vermont and Massachusetts Railroad. As a partner in the firm of Dillon & Pratt he was interested in the construction of 7 miles of the Rutland and Burlington Railroad near Burlington, Vt. A little later Boody, Ross & Dillon built the Central Railroad of New Jersey from Whitehouse to Easton, a distance of 29 miles, taking their pay entirely in stocks and bonds. The work was difficult, but was finished in two years by means of steam shovels. The firm was also engaged about the same time in widening 20 miles of the Morris Canal, and a little later contracted to build the Boston and New York Central road. The latter company failed after 30 miles were built, and the contractors were forced to attach and sell the rolling stock and other visible assets to obtain part of the money due them. Afterwards the company built 100 miles of the Philadelphia and Erie road west from Lock Haven ; and, somewhat later, Mr. Dillon was interested, as a member of the firm of Dillon, Clyde & Chapman, in contracts on the Erie and Cleveland, the New Jersey Central and the Mooris and Essex Railroads.

In 1865 he began his active association with the Union Pacific Railway, and during the next four years his wide experience as a railroad builder was of much value to the men in charge of that great enterprise. He was present at the ceremony of laying the last rail in 1869, and the silver spike with which the road was completed remained in his possession until his death. During this time he was also interested with John I. Blair in Iowa railroads, and had a 70-mile contract on the

construction of the Boston, Hartford and Erie Railroad, which, however, was not completed on account of the lack of funds of the railroad company. A little later he had contracts on the Connecticut Valley, the Chillicothe, Council Bluffs and Omaha, and the Canada Southern roads, built the Paterson branch of the Morris and Essex line and was engaged on many smaller works.

All these contracts brought Mr. Dillon a large fortune, which was principally invested in railroad securities. The management of these investments gradually occupied a larger part of his time, and after 1870 he was known chiefly as a financier. He was a director of the Union Pacific Company for many years and its president during a considerable part of this time. He was associated with Jay Gould in the management of many of the properties controlled by the latter, and was a director in the Western Union Telegraph, the Manhattan Elevated Railroad, the Missouri Pacific Railway, the Pacific Mail Steamship, the Chicago, Rock Island and Pacific Railway, the Wabash Railway, the Canadian Southern Railway, the Wheeling and Lake Erie Railroad Companies and many smaller organizations.

Mr. Dillon was elected a Fellow of the American Society of Civil Engineers on March 26th, 1870. He was married in 1841, and left two daughters, four grandsons and one granddaughter.